
A
SYSTEM
OF
CHEMISTRY.

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CHEMISTRY.

BY
J. MURRAY,
LECTURER ON CHEMISTRY, AND ON MATERIA MEDICA
AND PHARMACY, EDINBURGH.

IN FOUR VOLUMES.

SECOND EDITION.

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J. M. R. B. A. S.

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AND PHARMACY, LONDON

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SYSTEM OF CHEMISTRY.

BOOK VI.

OF METALS AND THEIR COMBINATIONS.

THE chemical history of no class of substances is more important than that of the Metals, from the multiplicity of their combinations, and the numerous uses to which they are applied. Their chemical relations have been still farther extended, and rendered still more important, by the recent discoveries with regard to the alkalis and earths, the bases of these being proved to be of a metallic nature. With the exception of oxygen, the metals are now perhaps the only substances which have not been decomposed, or which there is not the strongest reason from analogy to believe are compounds; for it is not improbable that hydrogen is a metallic body in the gaseous form, and that the bases of the primary inflammables are of a metallic nature. And the present state

of chemistry affords grounds for the conjecture, that oxygen and metals form two classes opposed in their chemical actions, and which, by their combinations, give rise to all existing compounds.

Having, for the reasons which have been already stated, considered the bases of the alkalis and earths, under the accounts of these substances, I have in this book to proceed to the history of the substances which have been more peculiarly denominated Metals. The number of these has been much augmented by the researches of modern chemists. Seven metals only were known to the ancients, a few were discovered during the dark ages, and twenty-seven or twenty-eight bodies are now referred to this class.

In strict definition, the metals are inflammable bodies; for they combine with oxygen, and many of them, during this combination, exhibit the phenomena of combustion, or emit light and caloric. But they are distinguished from other inflammables, and indeed from every other class of chemical agents, by very appropriate qualities,—great specific gravity, considerable tenacity and hardness, opacity, and the property of reflecting the greater part of the light which falls on their surface, giving rise to what is more peculiarly denominated the metallic lustre or brilliancy.

Of these characteristic physical properties of the metals, none is more so than their great density and consequent superior specific gravity. In this they exceed all other bodies, some of them being nineteen or twenty times heavier than water, and the lightest having a specific gravity above 6, water being 1. It is doubtful, however,

whether this can now be regarded as a peculiar metallic property, the bases of the alkalis, which have all the other metallic qualities, being of a specific gravity much inferior even to that of water.

Opacity is another property characteristic of the metals. They are, if not absolutely opaque, very nearly so; as when beat extremely fine, they transmit no light. Gold leaf, when beat to the greatest thinness of which it is susceptible, transmits a beautiful green light. It has been doubted whether this is not owing to minute fissures, occasioned by the beating, through which the light in passing suffers refraction; but such fissures ought to occur in the other metals beat to their state of greatest tenuity; and the cause why light is capable of being transmitted only through gold, is no doubt that from its greater malleability it can be reduced to much finer leaves.

From the conjunction of these qualities, density and opacity, arises another characteristic property of the metals,—that of lustre or brilliancy. By their opacity, and the denseness or closeness of their texture, they are enabled to reflect the greater part of the light that falls upon their surface. From their density they are susceptible of a fine polish, by which their lustre is increased.

Colour is not a characteristic property of the metals, but it is possessed by them, and serves to distinguish them from each other. Their colours are generally shades of white, grey, or yellow.

Tenacity, or the strong cohesion of their particles, distinguishes a number of the metals, and is not possessed in any great degree by other bodies. It gives rise to two

properties, malleability and ductility, somewhat analogous to each other, but which are still distinct. Malleability is that property from which they may be beat or pressed into fine plates or leaves, without having their texture injured; ductility, that by which they may be drawn into fine wire. The reducing them into thin leaves is performed, either by a strong and uniform pressure applied by a roller, or by beating with a hammer. The drawing them into fine wire, is done by means of a metalline plate, in which there are conical holes of different diameters. The metal to be drawn out is made into a cylinder, which, being smaller at the extremity, is introduced into the largest aperture, and is drawn through by the aid of machinery. It is then made to pass through the smaller apertures, till it is obtained of the requisite fineness. In either of these operations, the metal is liable to break when it is reduced to a certain degree of tenuity; and when this happens, the operation cannot be carried farther. But this is remedied by annealing the metal, or heating it, and allowing it to cool slowly; it then becomes again capable of being farther extended.

The malleability of the metals is estimated by the thinness to which a certain quantity can be beat out without any fissure;—the ductility, by the fineness of the wire into which the metal can be drawn. Though these properties are connected, they are possessed in different proportions by the metals. Gold is the most malleable, but in ductility is inferior to iron, platina, silver, and copper. Iron exceeds the others in ductility, but is scarcely malleable. Tin and lead have considerable malleability, but little ductility. Some of the metals are neither malleable

nor ductile. These were named Semi-metals ;—an improper distinction, which is now disregarded.

The cause of the tenacity of metals, whether under the form of malleability or ductility, has been supposed to be a peculiar state of their particles in relation to the force of cohesion, allowing them to move with regard to each other, without passing the limits at which this force is exerted ; or, in the language of Häüy, “ it is owing to the particles having the faculty of yielding to pressure, by sliding over each other, in such a manner that the points by which they are attracted, although really displaced, are always at distances so small that the adhesion remains *.” The difference between ductility and malleability has been ascribed to the figure of their particles, and their arrangement. The malleable metals may be conceived to consist of small plates, and the ductile metals of minute fibres, placed beside or over each other ; the one slide by their flat surfaces, the other lengthen and exert an adhesion from one extremity to the other †.

In Hardness the metals are surpassed by the diamond, and by a number of the earthy fossils, which scratch them easily, and some of which, in powder, are employed, from this superior hardness, to polish even the hardest of the metals. Still some of them, such as platina and iron, are considerably hard. Their elasticity follows the same order as their hardness. Both these qualities are greater in combinations of the metals than in the individual me-

* *Traité de Mineralogie*, tom. iii. p. 348.

† *Fourcroy*, vol. v. p. 20.

tals; and both may be much increased, by raising the metal to a high temperature, and then suddenly cooling it; that state of aggregation being thus induced, from which these qualities arise, and by which the ductility and malleability are impaired. The tenacity and softness are restored by again heating the metal, and allowing it to cool gradually.

Metals, in their relations to caloric, have some peculiarities, though in these they differ much from each other. They are the best conductors of this power. Their expansibilities are various, and are probably nearly in the order of their fusibilities. With regard to fusibility, they differ greatly. Mercury melts at so low a temperature, that it can be obtained in the solid state only at a very intense cold, nearly 40° below the commencement of Fahrenheit's scale; others, as platina or molybdena, can scarcely be melted by the most intense heat which, by any arrangement, we have it in our power to excite, and between these extremes is a series in which the degrees of fusibility are very various. A metal in its melted state still retains the qualities of opacity and brilliancy, and the lustre is even greater, as the surface is perfectly smooth. In congealing, some of the metals expand considerably, especially iron, bismuth, and perhaps antimony; and the expansion of iron appears to commence even above the point at which its actual solidification takes place. All the others, according to the experiments of Reaumur, contract; and the contraction of some of them is very considerable, that of mercury, for example, being equal, according to the calculation of Cavendish, to $\frac{1}{27}$ of its volume.

In congealing, a crystalline arrangement, more or less distinct in the fracture of the metal, is assumed ; and by particular management a number of the metals may even be regularly crystallized. The process consists in allowing the melted metal to cool slowly, and, when the mass has become solid at the surface, piercing the thin crust, and withdrawing the internal liquid part. The internal surface of the crust exhibits crystals more or less regular, which in the different metals are nearly of the same figure, that of a pyramid, single or double, of four sides. In some metals, however, as zinc, the figure of the crystals is a prism*.

By a heat, more or less strong, the metals may be volatilized. The volatilization of quicksilver is effected at a temperature of 660° , as is that of zinc and arsenic at a temperature not very remote from this ; and a number of the others are dissipated in vapour in the intense heat excited in the focus of a large burning mirror, or by a powerful galvanic discharge. It is even possible, that metals may exist at natural temperatures in the aerial form ; and I have already remarked, that hydrogen, under this point of view, may be a metallic body, or contain a metallic base.

A distinguishing property of metallic bodies is that of generating galvanism by mutual contact, especially when certain chemical agents are likewise placed in the series. They are also the best conductors of electricity, evolved under its usual forms.

* Journal de Physique, 1781, p. 74.

Metals are very susceptible of combination : they exert affinities to oxygen, to hydrogen, carbon, sulphur, phosphorus, and to each other ; and when combined with oxygen, to the acids, the alkalis, and the earths. On these combinations, some general observations may be offered, previous to the history of the individual metals.

Their combinations with oxygen are the most important, not only from the phenomena they exhibit, but from the important influence of this principle on the affinities which the metals have to other chemical agents.

When a metal is exposed to a high temperature, with the access of atmospheric air, it begins to suffer an evident change, more or less rapid, in different metals : its surface becomes dull : the metallic lustre is at length entirely lost ; and if the metal suffer this change while it remains solid, thin scales form on its surface ; if it be in fusion, its surface is covered with a powder, which has none of the characteristic metallic properties. On removing this, the metal beneath is found bright, but it continues to undergo the same change, and thus the whole of it may be successively converted into this new matter.

This process was by the older chemists named Metallic Calcination, and the product was called a Metallic Calx. The phenomena were explained in conformity to the theory of Stahl ; for the speculations of Rey, Mayow, and Hooke, on this subject, had been altogether neglected. Metals having an evident relation to inflammable bodies, and some of them even in the above process exhibiting phenomena analogous to those of combustion, were supposed to contain phlogiston, or the common principle of inflammability, or they were regarded as com-

pounds of this principle with certain bases. During their calcination, Stahl supposed that this principle was expelled, and that the earthy-like powder which remained, or the calx, was the base with which the phlogiston had been combined. In conformity to this theory, and what was regarded as a confirmation of it, if any of the metallic calces were exposed to heat, mixed with a portion of inflammable matter, it was reduced to the metallic state, the phlogiston essential to this state being transferred, as was supposed, from the inflammable body to the metallic base.

One obvious objection to this theory, which might have been urged even at the time that it was implicitly received, was, that it did not account for the necessity of the presence of the atmospheric air to metallic calcination. And another fact, ascertained at least with regard to some metals even before the time of Stahl, which it failed in explaining, was, that the metal by calcination, when according to the hypothesis it lost a principle, increased in weight; 100 lbs. of lead, for example, affording 110 lbs. of calx.

The fallacy of the hypothesis was at length demonstrated by the researches of Lavoisier and Berthollet. The former chemist, led by his views with regard to the phenomena which were embraced by the theory of Stahl, to ascribe metallic calcination, not to the escape of phlogiston, but to the absorption of a part of the air, advanced that opinion in a memoir read before the Academy of Sciences, and published in 1774; and supported it by urging the increase of weight in metallic calces, compared with the metals from which they are formed, by shewing that metallic calcination requires the presence of

air, which during the process suffers a diminution of volume, and by ascertaining, that when the calx is reduced, by heating it with charcoal, to the metallic state, a large quantity of elastic fluid is disengaged. Bayen had nearly about the same time been engaged in similar researches on the calces of metals, particularly those precipitated from solutions of the metals in acids. He shewed that the weight of these was greater than that of the metal dissolved, and inferred, that although part of this weight was owing frequently to a portion of the acid, by which the metal had been dissolved, adhering to the precipitate, it was also in part owing, adopting an expression employed by Lavoisier, to an elastic fluid fixed in the metal. To prove this, he examined more particularly the phenomena which occur in their reduction. He found, that when reduced, by heating them with charcoal, much elastic fluid is disengaged; and what afforded the most direct demonstration of the theory he had begun to entertain, he at length succeeded in reducing some of these calces, particularly those of mercury, by heat alone in glass vessels, and obtained a large quantity of air during the reduction *. Priestley afterwards found, that the air which is obtained by heat from calcined mercury is pure oxygen; and the discovery of this gas enabled Lavoisier to complete the theory of metallic calcination, which he now ascribed to the combination of the metal with oxygen. This he established by a series of extensive and accurate experiments, performed with this view. He proved, that the calcination of a metal cannot proceed

* Journal de Physique, 1774.

without the presence of oxygen; that the oxygen present disappears; that the weight which the metal uniformly gains in its calcination, is equal to the weight of the oxygen which is consumed; and that this oxygen can again be obtained from the calx, which then returns to the metallic state; in some cases, by the operation of heat alone, when the oxygen is obtained pure; in others, by heating it with an inflammable substance with which the oxygen combines, affording the known product of such a combination. The old terms of Calx and Calcination were disused, as conveying erroneous ideas, and were succeeded by those of Metallic Oxide, and Metallic Oxidation.

The principal difference in the phenomena exhibited by the metals during their oxidation by exposure to heat and atmospheric air, is in the slowness or the rapidity with which it takes place. In general, they combine slowly with the oxygen of the air: they do not render sensible much caloric, or emit light, and therefore do not present the appearances of combustion. This is the case with lead, quicksilver, and indeed with the greater number of them. In some, however, the oxidizement is more rapid, and is even accompanied with a vivid combustion, as in the example of zinc. If the temperature be raised considerably above that which is merely requisite to the slow calcination, the combustion is so far promoted as to be accompanied with an evolution of light, which does not take place at a lower temperature. Thus tin burns at a high heat with a white light, antimony with a yellow, and copper with a green light. Iron in oxygen gas burns with great splendour: and by the intense heat excited by a powerful galvanic apparatus, even gold and silver may

be made to undergo combustion, the silver burning with a vivid white light, the gold with a bright yellow.

The facility or difficulty of oxidation of the metals is regulated by various circumstances. It depends not merely, as was once imagined, on the force of their affinity to oxygen; but on that force, modified by their cohesion; their consequent fusibility and volatility; the condensation into which the oxygen passes when it combines with them; and the quantity of caloric it retains in passing into this combination.

Of these circumstances the cohesion is the most important; and as this is very considerable in the metals, we discover the cause why few of them are susceptible of oxidization but at a high temperature. A number of them require to be in fusion to admit of the combination. Some of them, however, as iron and copper, are oxidized when exposed to a red heat, though this is not sufficient to melt them; their surface is slowly tinged with various colours, and at length scales of oxide are formed. Even when in fusion, several of them require the cohesion to be still more diminished by the operation of caloric, to enable them to attract oxygen; and some, as antimony and quicksilver, must be raised to their vaporific point. Gold, silver, and platina, can scarcely be directly combined with oxygen; and hence, suffering no change when exposed to very intense heats, they were formerly named Indestructible Metals. The reason is, not that they have no affinity to oxygen, for we can combine them with it by indirect methods; but that, having much cohesion, and perhaps an affinity comparatively weak, this cohesion resists the combination, and when

heat is applied to overcome it, the elasticity of the oxygen gas is at the same time augmented, and the attraction is not sufficiently powerful to enable them to fix it. But if the cohesion be weakened, or fluidity communicated, without raising the temperature, as by dissolving them in quicksilver, their oxidation may be effected; as it is also, if a very intense heat be suddenly applied, Hence their oxidizement, by a powerful electric discharge, as shown in the experiments on the oxidation of metals by electricity by Mr Cuthbertson *, and their combustion when exposed to the action of a galvanic battery.

It is not easy to assign the order of the affinities of the metals to oxygen, from the difficulty of appreciating with accuracy the effect of the circumstances by which their combination is influenced. Judging from the comparative difficulty or facility of decomposition, manganese, molybdena, iron, and zinc, appear to have the most powerful attraction towards it, as their oxides are decomposed with difficulty by charcoal, assisted by a very strong heat. The oxides of copper, lead, bismuth, and arsenic, are reduced to the metallic state by the agency of hydrogen; and the oxides of quicksilver, silver, and gold, are decomposed by heat alone. A metallic oxide may be decomposed by the action of another metal; as the oxide of copper by heating it with zinc, and the oxide of quicksilver by iron, which affords some indication of the relative attractions.

The different metals attract very different quantities of

* Nicolson's Journal, &c, vol. v. p. 136.

oxygen, which, according to Berthollet's view of the strength of chemical affinity, may be considered as indicating the order of attraction; and the order thus indicated, agrees in a general point of view with that inferred from the difficulty of decomposition. 100 grains of the perfect oxide of iron, contain 48 of oxygen, of that of manganese 40, of tin 28, of lead 21, of copper 20, of bismuth 17, of quicksilver 15, of silver not more than 10 grains.

Not only do the different metals attract different quantities of oxygen, but the same metal combines with different proportions, or is susceptible of various degrees of oxidizement. Each of these degrees is marked by an alteration of properties. Even in the first degree of oxidizement, the metallic properties are lost; and the successive degrees are marked by the acquisition of new properties, so that two oxides of the same metal are frequently very dissimilar. Changes of colour generally indicate the various degrees of oxidizement. The colour in the first stage often approaches to that of the metal; in higher degrees, it becomes more brilliant or white.

It was an opinion generally received among chemists, that these combinations of a metal with oxygen, take place in determinate proportions, and that between these there are no intermediate combinations. Thus we can prepare an oxide of iron of a black, and another of a red colour, the former containing 27 of oxygen in 100 parts, the other 48; and the oxidizement of iron was supposed to be confined to these two proportions. In like manner, there were supposed to be only two oxides of gold, a purple and a yellow; two oxides of manganese,

a white and a black ; and thus, in general, two degrees of oxidizement were assigned to the metals. This opinion has been in particular maintained by Proust *. Other chemists supposed that the combinations of the metals with oxygen always take place in determinate proportions, but allowed that there might be more than two oxides of the same metal. This view of the subject has been supported by Thenard †.

These opinions have been called in question, and apparently with much reason, by Berthollet. He has maintained, that the proportions may vary progressively from the term at which the combination of the metal with oxygen becomes possible, to that at which it requires the highest degree of oxidizement, where the combination is stopped from the diminution in the force of affinity; that in many cases it does so ; and that if, in others, determinate proportions are observed, this is owing to the operation of circumstances, which, at these proportions, limit the combination, and which in general being uniform, give rise to an invariable proportion ‡.

It is no doubt true, as Thenard has urged, that as sulphur or phosphorus combine with oxygen in certain fixed proportions, the same law may be observed in the oxidation of metals. But even these proportions, with regard to the former substances, are probably fixed by the interference of foreign forces, as has already been explained. The tendency of attraction between bodies appears to be

* Journal de Physique, tom. lix. p. 321.

† Annales de Chimie, tom. lvi.

‡ Chemical Statics, vol. ii. p. 316.

always to unite them in any proportion what ever ; and it is only by the operation of such forces, that these proportions are rendered determinate. Confining the discussion to the question as it relates to the metals, the opinion of Berthollet will be found better supported by facts than that which is opposed to it. Manganese, at the maximum of oxidizement, forms an oxide of a black colour : at the minimum, one of a white shade : the black oxide is decomposed, at least partially, by heat, the oxygen being expelled ; and according to the intensity of this heat, more or less oxygen is expelled ; and numerous shades of colour may be obtained, warranting, therefore, the conclusion, that the decomposition is here not limited to determinate proportions, but is indefinite, or at every proportion between the two extremes. The oxide of iron, in like manner, passes by the action of heat, by numerous transitions from red through purple to black ; or, by triturating red oxide of quicksilver with metallic quicksilver, in various proportions, different shades of greyish yellow are obtained. In all these cases, the obvious inference is, that the combination is not determinate or definite. And it is a very strained hypothesis advanced by Proust to obviate this conclusion, that these different shades arise from the reduction of part of the oxide at the maximum of oxidizement to that at the minimum, and the mechanical intermixture of these two oxides in various proportions ; for why, when the whole oxide has been heated to the same temperature, should it not all have been reduced to the same extent ?

There can be no doubt, however, but that the proportions of metallic oxides are often determinate, owing to

the operation of circumstances nearly uniform in themselves, by which the combination is regulated. The fusion of a metal affords an example of this. If a metal be oxidated at the point at which it melts, as that point is not variable, the oxide will always be uniform, or one determinate proportion will be observed in the combination. For the same reason, the oxide which is formed at the vaporific point of a metal will be always the same; and the affinities of acids, as is immediately to be explained, often determine the combination, or place limits to the proportions in which it takes place. Hence salts are often formed from these combinations perfectly uniform, or having an oxide of the same composition; and it may be true, what is stated by Thenard, that there are sulphates of iron formed from three oxides of determinate composition, without the opinion advanced by Berthollet being subverted.

From the various degrees of oxidation of which metals are susceptible, there is some difficulty in establishing a nomenclature with regard to their oxides, so as to distinguish, with precision, the different oxides of the same metal. In the nomenclature framed by the French Chemists, this was generally done from the colour, which in the different degrees of oxidizement is various; and hence were introduced the expressions, red oxide of mercury, grey oxide of mercury, black oxide of iron, &c. This method is perhaps somewhat vague. It has even been supposed, that different oxides of the same metal are, in some cases, of the same colour; though of this there is much reason to doubt. A more precise nomen-

clature, which should have the advantage of expressing the series of oxidizement, could it be introduced, would, however, be desireable ; but it is impracticable. If the conclusion above stated, that the metals are susceptible of indefinite degrees of oxidizement, be just, it is obvious, as Berthollet has remarked *, that no nomenclature, founded on specific degrees, or on a determinate progression with regard to proportions, can be received ; and even were it admitted to be determinate, the discovery of a new oxide of a metal would, in such a nomenclature, change the whole series of names, and the progress of the science would give rise to the utmost confusion. The only source of distinctions, therefore, is in the qualities of the oxides themselves ; and of these, colour will be found the most striking, and the most uniformly varied in the different oxides : though, should the distinction from it be in any case ambiguous, it ought to be drawn from some other quality which may not have this disadvantage.

In their general properties, the metallic oxides have a considerable resemblance. They are destitute of the metallic lustre, opacity, and gravity : they are uninflammable ; generally tasteless, and insoluble in water ; have an earthy appearance ; are less fusible than their respective metals : when fused, they generally form coloured glasses : they are also often less volatile, a proof of the great condensation which has attended the combination.

There are some metals capable of being so highly oxidized, as to pass to the acid state ; such are arsenic, molybdena, chrome, and perhaps tungsten.

* Chemical Statics, vol i. p. 453.

The process by which the metallic oxides are decomposed, and the metal recovered in its original state, is named in chemical language Reduction. It is effected by various means.

Some suffer it by exposure to heat ; as the oxides of gold, silver, and quicksilver. Their oxygen is expelled at the temperature of ignition, and the metal returns to the metallic form. With regard to others, the decomposition by heat is partial, or the affinity of the metal to oxygen is such, that though at first part of the oxygen assumes the elastic state, yet as the affinity of the metal is aided by the relative increase in its proportion as the decomposition proceeds, it becomes at length sufficiently strong to put a stop to it ; and even by the most intense heat, the whole of the oxygen cannot be expelled.

The decomposition can always be effected by the operation of other affinities. Hydrogen is capable of abstracting the oxygen from some of these combinations ; the oxide being placed in hydrogen gas, and an elevation of temperature being produced by the concentrated solar rays. Charcoal, or some carbonaceous substance, is generally employed as the medium of metallic reduction, and is capable of reducing the oxide of every metal.

In practical chemistry, some other additions are found necessary or useful. These are of substances which may promote the fusibility of the metallic oxide, and thus favour the action of the charcoal upon it. On a large scale, lime is generally employed : in experiments on a small scale, potassa is used under the form of what has been named the Black Flux. This is prepared by exposing to heat, in an ignited crucible, a mixture of one

part of nitrate of potassa, with two parts of the crude tartar of commerce,—an impure tartrate of potassa. It consists of sub-carbonate of potassa and charcoal, the carbonaceous matter being derived from the decomposition of the tartaric acid, of which carbon constitutes a principal part. Equal parts of this black flux, and of the oxide intended to be reduced, are mixed together. The potassa favours the action of the charcoal on the metallic oxide, probably by promoting the fusion of the latter: the charcoal attracts the oxygen of the oxide, forming, according to circumstances, either carbonic acid or carbonic oxide: the first being chiefly produced when the metal has a weak attraction to oxygen, the second where the attraction is stronger; and being more free from carbonic acid, as Cruickshank observed, towards the end, than at the commencement of the experiment.

Besides the oxidizement which metals suffer when exposed at a high temperature to the action of oxygen in its elastic form, they can be subjected to the same combination by substances containing oxygen, from which they are capable of attracting it. They are thus brought to the state of oxides by nitrate of potassa, oxymuriate of potassa, by acids, and by water.

The first requires the assistance of a high temperature. The nitric acid of the nitrate is then decomposed with more or less rapidity, and part of its oxygen attracted by the metal; forming generally that oxide in which the metal is at the maximum of oxidizement, and with which the potassa sometimes combines. All the metals may be oxidated by thus exposing them to a high temperature, in mixture with nitrate of potassa; even gold,

silver, and platina, which are combined with oxygen with most difficulty, as was known to the older chemists, and as has been more lately established by Mr Tennant*.

The oxidizement of metals by the oxy-muriate of potassa, is effected by percussion, without the aid of a high temperature, and is so rapid as to be attended with detonation, and to be made with safety only on small quantities of the ingredients.

Several of the metals receive oxygen from water, though the process, at a low temperature, goes on slowly. If iron-filings, moistened with water, be placed over quicksilver in a close vessel, the metal is oxidated, and hydrogen is evolved. At the temperature of ignition, this decomposition of the water and oxidation of the metal proceed with rapidity. Not only iron, but zinc, manganese, tin, and perhaps antimony, suffer it.

Acids are much more active in oxidizing the metals, partly from yielding oxygen with more facility, and partly from the attractions which the acid at the same time exerts. These actions present striking, and somewhat complicated phenomena, and from this, as well as from their importance, require some details.

Acids oxidize the metals, either by directly affording to them part of the oxygen they contain, or by enabling them to attract oxygen from water, or in some cases from the atmospheric air.

The acids which act in the first of these modes, will obviously be those in which the oxygen is not retained by a strong attraction; such are principally the nitric

* Philosophical Transactions, 1797.

and the oxy-muriatic acid. If the nitric acid be poured on a metal, it is generally decomposed with rapidity, and by different metals, with different degrees of energy; nitrous oxide, nitric oxide, or even nitrogen, being evolved in the elastic form. A circumstance extremely singular attending these actions, and of which a satisfactory explanation has not yet been given, is, that if the acid be concentrated, it is not decomposed by some of these metals; but if a little water be added, or if the acid has been previously a little diluted, the decomposition proceeds rapidly. Oxy-muriatic or nitro-muriatic acid affords oxygen to the metals with still more facility, as is displayed in their action on gold, which even nitric acid does not oxidize, or does so very sparingly, and with much difficulty.

There are few of the metals capable of attracting oxygen from the sulphuric acid, unless assisted by a high temperature, which diminishes their cohesion, and favours the transition of the sulphuric into sulphurous acid. When aided by a sufficient elevation of temperature, iron, zinc, copper, tin, quicksilver, and others, are oxidized by it. The phosphoric acid is of more difficult decomposition, and hence acts with less energy on the metals.

In other cases, the metal is oxidized by the acid enabling it to decompose the water present. This is well exemplified in sulphuric acid, which in its concentrated state acts feebly on even those metals which appear to have the strongest attraction to oxygen, as zinc or iron, at a low temperature; but if diluted with water, the action is violent, and attended with the copious evolution of hydrogen gas from the decomposition of the water.

It is only in this way, too, that muriatic acid or fluoric acid acts on the metals, as either of them is incapable of directly affording oxygen. Nitric acid is so easy of decomposition, and the elementary affinity exerted between the metal and its oxygen is so much stronger than the resulting affinity between the acid and the metal, that it is decomposed, and the metal receives oxygen from it alone. There are some metals, however, which have such an avidity to oxygen, that when acted on by nitric acid, both the acid and the water suffer decomposition; the oxygen of each is attracted by the metal; and the nitrogen of the acid and hydrogen of the water being presented to each other in their nascent state, form ammonia.

The powerful effect of an acid in enabling a metal to decompose water, and receive from it oxygen, is exemplified in the decomposition being so rapid at a low temperature; and still more so by the fact, that some metals decompose water when aided by this affinity of the acid, which of themselves are unable to effect this decomposition at a high temperature. Such are tin and arsenic.

The agency of the acid in promoting this decomposition, is owing, as has been already explained, to the affinity it exerts to the metal and the oxygen, which, conspiring with the affinity of the metal to oxygen, overcomes the simple affinity of the oxygen and hydrogen, and unites the metal, the oxygen, and the acid, in one combination.

Lastly, acids enable metals to combine with oxygen in the elastic form, or to attract it from the atmosphere. This has generally been supposed to happen with those metals which have a weak attraction to oxygen, and those

acids the action of which is not energetic, as in the examples of lead or copper, acted on by acetic acid. If the air is excluded, these metals are not dissolved by this acid; but if partially immersed in it, and exposed to the atmosphere, the metal is oxidized, and dissolved at the surface, where it is exposed to the joint action of the acid and the atmosphere. From some experiments made at an early period by Dr Irvine, it appears, that even in the more rapid action of the acids on metals, oxygen is absorbed, either by the metal, or by the product of the decomposition acting in its nascent state, there being a small increase of weight, notwithstanding the escape of elastic products, during the solutions of silver and quicksilver in diluted nitric acid, and of zinc in diluted sulphuric acid*.

When a metal has been brought to the state of an oxide, it becomes capable of combining with the acids, and exerts to them affinities of considerable force. No metal in its pure state unites with an acid; it must always be previously oxidized. To this there is no exception; and it is a truth of much importance in explaining the phenomena of metallic solutions. A metal subjected to the action of an acid, first attracts oxygen, either from the acid, the water, or the atmospheric air, and then combines with the acid; and hence all solutions of metals in acids are, properly speaking, solutions of metallic oxides. A similar combination is therefore at once formed, if the metal previously oxidized is added to the acid. The necessity of oxidization to a metal com-

* Essays on Chemical Subjects, p. 423.

bining with oxygen, appears to arise, not, as was supposed, from the absence of all attraction between acids and metals, but partly, as has been already explained *, from the cohesion of the metal in its metallic state being too great to admit of the mutual affinity being mutually exerted, and partly from the elementary affinity of the metal to oxygen being stronger than the resulting affinity of the metal to the acid ; whence, if any action results, it is first the oxidizement of the metal, and then the combination of the oxide with the acid.

The combinations of the metallic oxides with the acids are of a saline nature, or are similar in their general properties to the compounds formed by the acids with the alkalis or earths, the acid properties being neutralized, and the compound being often soluble in water, and crystallizable. From this strict analogy, these compounds have always been regarded as saline, and the analogy is now more evidently strict, since the bases of the other salts are in fact metallic oxides. Their nomenclature is similar to that of the other compound salts. They are named, according to the acid which enters into their composition, *sulphates*, *nitrates*, *muriates*; as sulphate of iron, nitrate of copper, muriate of quicksilver, &c. As the oxide of the metal, rather than the metal itself, is the base with which the acid is combined, they ought in strictness to have been named sulphate of oxide of iron, or sulphated oxide of iron, &c. ; but the other nomenclature has been preferred, from being more concise, and more analogous to that of the other compound salts.

* Vol. I. Note, A. d.

As the metals can combine with different proportions of oxygen, they may exist in combination with the same acid in different states, more or less oxidized, giving rise therefore to different salts. On this subject some important facts require to be stated.

If a metal be acted on by a diluted acid, or one of little energy of action, the combination formed is generally that of the metal in an imperfect or low state of oxidizement; while, by a more powerful or concentrated acid, the metal is more highly oxidized. Or, if the action be favoured by heat, the acid is more completely decomposed, and the metal receives more oxygen than when the solution proceeds at a natural temperature.

Even after a metal has been dissolved in an acid, it may continue to attract oxygen from the atmospheric air; and hence the changes which a metallic solution often spontaneously suffers. This is the case principally with those which have a strong attraction to oxygen, as iron or tin; while the solutions of those which have a weaker attraction, as gold or silver, remain permanent.

In general, it appears, that the action of the acids on the metallic oxides is less powerful as the degree of oxidizement is greater. A metal, therefore, saturated with oxygen, will frequently not remain in combination, or at least exert a very weak attraction to an acid with which, when less highly oxidized, it unites intimately. From this are explained the changes many metallic solutions undergo from exposure to the air. The metal in solution continues to attract oxygen, and its action on the acid becoming progressively weaker, it at length can retain only a small portion in combination, and falls down as

insoluble precipitate. If we expose, for example, a solution of sulphate of iron to the atmosphere, although the acid has by its action a tendency to maintain the metal in the state in which it exerts the most powerful attraction to it,—that in which it is least oxidized; yet such is the attraction of the iron to oxygen, that it absorbs it from the atmosphere, and approaches to the higher degrees of oxidizement. As it does so, the action of the acid on it diminishes; and thus at length a portion of the oxide, with a small quantity of the acid combined with it, precipitates, while the excess of acid remains in the liquor, with a small portion of the metal less oxidized, and which the acid, by its quantity adding to the force of its affinity, preserves in that state. Similar changes are also produced by exposing a metallic solution to heat; a portion of the acid in it suffering decomposition, and the metal acquiring more oxygen.

On the same principle,—that the acids exert a less powerful action on the metals, when in a high than when in a low state of oxidizement, may be explained the fact, that some metallic oxides are insoluble in sulphuric, nitric, or oxy-muriatic acid, while they are dissolved by the sulphurous, nitrous or muriatic acid; the latter acids being capable of abstracting a portion of oxygen from the oxide, and thus bringing it to that state in which its affinity to the acid can be exerted. To this principle may likewise be referred another important fact, which appears to be established by the experiments of Guy Lussac, that a metallic oxide may precipitate either a different oxide of the same metal, or an oxide of another; the metal less highly oxidized precipitating always the one in the higher

state of oxidizement. An extensive series of decompositions can thus be effected, some of them applicable to useful purposes*.

It has been already remarked, that the metals appear in general to be not liable to determinate degrees of oxidizement, but to combine with oxygen indefinitely between the minimum and maximum of that state. Do they observe the same law in combining with the acids, or can they enter into such combinations only when they are in determinate degrees of oxidation? This is a very important question, not only theoretically, but likewise from its relations to pharmacy and some of the arts.

The opinion, that the metals enter into combination with the acids, in determinate degrees of oxidizement, has in particular been maintained by Proust †, and more lately by Thenard ‡. There can be no doubt that this law is frequently observed, and that the acid, by the energy of its action, causes a determinate oxidation, and unites with the oxide thus formed; or that the force of cohesion or insolubility determines the combination in certain proportions. Thus quicksilver combines in two states of oxidizement with muriatic acid; nor, whatever process may be followed, does it ever appear to combine with it in any intermediate degree. But there is reason to believe, that the reverse is frequently the case, as Berthollet, in conformity to his views of chemical affinity,

* Nicholson's Journal, vol. viii. p. 270.

† Nicholson's Journal, 4to, vol. i. p. 453. Journal de Physique, tom. lix. p. 334.

‡ Philosoph. Magaz. vol. xxiv. p. 224.

has maintained, and that the acid unites with the metal in all the shades of oxidizement of which it is susceptible. We perceive this in the case of a metallic solution which absorbs oxygen from the air. The absorption is gradual, from the *minimum* to the *maximum* of oxidation; yet in no stage of the process is the combination of the oxide with the acid interrupted. The salts of iron have been supposed to consist of the metal in determinate degrees of oxidizement; one, the green sulphate, containing it at the *minimum*; the other, the red sulphate, at the *maximum*; and that between these there are no intermediate combinations. Yet Berthollet found, that on mixing solutions of these salts, an intermediate compound was formed, which the acid was unable to retain in solution. He has also remarked, that in the crystallization of sulphate of iron, the first crystals are nearly without colour; those which succeed in the subsequent crystallizations, assume more and more colour to a deep green; and at last there is a liquor not capable of crystallizing, which is in the state of highest oxidation. This proves, that a division of the oxygen is made during the course of the crystallization, and that the sulphate of iron which crystallizes has not fixed proportions of oxygen: it may be more or less oxidized, and it passes by insensible gradations from one state to the other. He has given a number of other observations in proof of the conclusion, that in many of these saline combinations, determinate degrees of oxidizement are not observed*.

The properties of the salts formed from the same me-

* Researches, p. 187. Chemical Statics, vol. ii. p. 346.

tal, in different states of oxidizement, united with the same acid, are extremely different. Thus quicksilver, in the state of an imperfect oxide, united with muriatic acid, forms a compound perfectly insipid, and insoluble in water; while the combination of what may be named the perfect oxide with the same acid, gives rise to a compound extremely acrid, and perfectly soluble. Iron, in one state of oxidizement, forms with sulphuric acid a crystallizable salt of a green colour; in another, a salt uncrystallizable, and of a reddish brown colour: and similar differences are found in the other metals.

There is no part of the modern nomenclature less systematic, than that which relates to these compounds of the same metal, in the different degrees of oxidizement with the same acid; for as the name of the genus is taken from the acid, and that of the species not from the real base, which is the metallic oxide, but from the metal itself, it is scarcely possible, by any variation of term, to express a variation in the base, the metal remaining the same. Accordingly, the distinctions have been drawn from differences of properties. The salts of the different oxides of the same metal often vary in colour, and from this their distinctive appellations have been drawn, as the green and the red sulphates of iron, &c. But it frequently happens, that the salts formed by the different oxides of the same metal with the same acid, do not differ in colour. Thus, there are two muriates of mercury, both of a white colour. A nomenclature which has been proposed to obviate this difficulty, and to be applied to all the metallic salts, is to prefix the syllable *oxy* to the name of that one in which the metal exists in the highest state of oxidizement. Thus, of the above salts of mercury,

the one would be named the muriate of mercury, the other oxy-muriate of mercury. In like manner we should have sulphate and oxy-sulphate of iron, nitrate and oxynitrate of tin, &c. There is, however, an important objection to this nomenclature, that the generic term is the same as that which is employed to denote the compounds of oxy-muriatic acid; and oxy-muriate of mercury implies a compound of oxy-muriatic acid with oxide of mercury, not a combination, as the salt actually is, of muriatic acid with mercury in a high state of oxidizement. Another deficiency of it is, that it can denote only two combinations of the same metal in different states of oxidizement, while it is possible there may be a greater number. Part of the difficulty on this subject, I may remark, has arisen from chemists having confined themselves to distinctive appellations drawn from colour. They may with equal propriety be drawn from any other property; and thus the salts of the same metal, even where the colour is the same, may be distinguished, and a nomenclature obtained, which, if not strictly systematic, is at least sufficiently correct. Thus, of the two muriates of mercury, one is mild and insipid, the other is highly corrosive; properties, from which in the old nomenclature distinctions were established between them. The same method may be transferred to the new: the one may be named the mild muriate of mercury, the other the corrosive muriate: and this may be extended to all the metallic salts; for it cannot happen but that, when the metal is really in different states of oxidizement, some differences in the properties of the salts must exist. We do not, indeed, from such a nomenclature, acquire any

knowledge of the chemical distinctions between these compounds ; but it serves to distinguish them from each other ; and it appears very difficult to construct a nomenclature which shall possess the other advantage.

Another important part of the chemical history of metallic solutions, is that which relates to the proportions in which the oxides combine with the acids. The metallic oxides, like the alkalis and the earths, have a tendency to combine with the acids, in such proportions as to produce mutual neutralization of properties ; and accordingly, a number of neutral metallic salts can be obtained, as sulphate of copper, sulphate of iron, muriate of quicksilver, and others. But the combination of an oxide with an acid is not limited to these proportions : they also often combine, so that there is an excess of acid, or an excess of base, forming compounds, therefore, which have very different qualities. In general, where there is a deficiency of acid, the compound approaches in its properties to the pure oxides ; and a number of such compounds have been mistaken for oxides. Where there is an excess of acid, it is difficult to obtain the compound in a crystallized, or even in a solid state. Rouelle, the celebrated French chemist, formerly pointed out the nature of these combinations * ; and his views, though they were in some measure neglected, are more just than those which were afterwards entertained.

These combinations of an oxide and acid in different proportions, are perhaps most evident in the decomposition, to which the neutral combination may be subjected,

* *Mémoires de l'Acad. des Sciences*, 1754.

on the one hand, by the partial abstraction of its acid ; on the other, by the partial abstraction of its base. The neutral sulphate of quicksilver, for example, may be obtained crystallized in slender prisms ; but it is easy to resolve it into salts, one with a deficiency, the other with an excess of acid. This is done merely by the action of water, which, exerting a stronger attraction to the sulphuric acid than to the oxide, subverts the composition of the neutral compound. The greater part of the acid is attracted by the water, but it retains combined with it a portion of the mercurial oxide, while the greater part of the oxide of mercury is on the other hand precipitated, holding an inferior portion of the acid likewise in combination. The neutral sulphate is thus resolved into two salts,—a sub-sulphate, and a super-sulphate ; and the existence of at least three sulphates of quicksilver is demonstrated. The case is the same with a number of other metallic oxides and acids.

It is an object of inquiry, whether these combinations of a metallic oxide with an acid take place in determinate, or in variable proportions. The same reasoning which leads to the conclusion, that in the oxidizement of metals, and indeed in chemical combinations in general, fixed proportions are not observed, unless where powerful determining circumstances act, leads to a similar conclusion with regard to the combination of these oxides with acids. This opinion has been maintained by Berthollet * ; and it is supported by a number of facts. Thus, in the case already stated for illustration,—the action of water on sulphate of quicksilver, if the sub-sulphate, which is at first

* *Researches*, p. 187. *Chemical Statics*, vol. ii. p. 342.

precipitated, be continued to be washed with water, it still continues to suffer decomposition ; a super-sulphate is abstracted by the water ; a number of degrees of sub-sulphate, and not one uniform combination, may be procured ; and this continues until the attraction of the oxide to the small remaining proportion of acid, is sufficient to counteract the affinity of the water to the acid. And even from this, the addition of an alkali might abstract a portion of acid, without, however, removing the whole of it.

The same thing is to be observed in the decomposition of a metallic salt by heat, in which numerous successive combinations are formed. Thus the nitrate of mercury passes, by many gradations, from a white salt to a mass of a yellow colour, and ultimately of a bright red.

These facts authorise the conclusion, that the metallic oxides may combine with acids in indefinite proportions. At the same time, it is to be observed, that circumstances often operate to render the proportions in these combinations determinate : the force of cohesion especially has this effect ; and, therefore, in a crystallized metallic salt, the proportions are generally constant and uniform ; and these will even be established by this cause from a solution where there is an excess of acid. Insolubility, which is nothing but the force of cohesion relative to the solvent, suddenly exerted, has the same operation. It is only, however, where such circumstances do act, that determinate proportions are established, otherwise they are variable, or the oxide and acid combine indefinitely.

In the order of attractions, those of the metallic oxides to the acids appear to be inferior to those of the alkalis and earths ; or, at least, the metallic salts are more susceptible

of decomposition. This facility of decomposition, however, appears to be owing, in a great measure, to the tendency of the metallic oxides to cohesion, and to the elementary affinity of the decomposing substance being so trivial to the oxide, compared with what it is to the acid; whence, instead of a resulting affinity being established towards the entire salt, it is decomposed.

With regard to many of them, the simple affinity of water to their acid is sufficient to decompose them. The water, however, although it abstract the acid, never does so entirely, but the oxide retains a portion still in combination with it, becoming, at the same time, generally insoluble; and, on the other hand, the acid, in combining with water, perhaps always retains a portion of the oxide in combination, in consequence of its affinity towards it; and the proportions thus established in these combinations, are much influenced by the quantity of water, to the action of which the salt is subjected.

Those metallic salts, which are not decomposed by water, may be decomposed by the alkalis, or by the more powerful of the earths. These decompositions present results somewhat complicated.

The general action of an alkali on a metallic solution, may be regarded as analogous to that of water, only more energetic. It causes its decomposition by the abstraction of the acid by the alkali. But this abstraction, though it may be to a greater extent than that by water, is still partial; or the oxide precipitated retains a portion of the acid, though perhaps an inconsiderable one. These precipitates have been frequently regarded by chemists as pure oxides; which they perhaps never are. That a portion of

the acid originally combined with them, remains in the combination, was shewn at an early period by Bayen, with regard at least to a number of them; and it has been confirmed by the researches of other chemists. And according to the quantity of alkali which is used, the precipitate will vary in its composition. Thus a little potassa, added to a solution of sulphate of copper, throws down a green precipitate, which Proust found to be an oxide of copper, with a portion of sulphuric acid; and which the experiments of Berthollet *junior* have shewn to amount to seven parts in 100. If more potassa be added, the precipitate acquires a blue colour; and this, according to the last chemist, contains less acid.

Potassa and soda act on metallic solutions in the manner now described. The action of ammonia is more peculiar, and is somewhat complicated. It has a much greater tendency to combine with the metallic oxides: hence, instead of merely precipitating them, it frequently, if added in sufficient quantity, redissolves the precipitate, forming with it and the acid of the salt a ternary compound. It also appears sometimes to decompose the oxide, its hydrogen attracting part of the oxygen, and reducing the oxide nearly to the metallic state.

Metallic salts may be decomposed by the action of an acid different from that which enters into their composition. Thus muriatic acid, added to a solution of nitrate of silver, decomposes it completely; the muriatic acid combining with the oxide of silver, and forming a compound which is precipitated; or sulphuric acid, added to nitrate of quicksilver, occasions a similar decomposition. Such decompositions may also be produced by double affinity.

They were formerly considered as arising from the different forces of affinity of the acids to the metallic oxides; muriatic acid being supposed to have the strongest; next to it the sulphuric and phosphoric; while that of the nitric or carbonic was much weaker. They are probably, however, in a great measure owing to the force of cohesion; and, accordingly, in all these cases, we find the superior affinity ascribed to that acid which forms with the metallic oxide the least soluble compound.

The last kind of decomposition of the metallic salts, of which it is necessary to take notice, is that which they suffer from the operation of another metal. It differs from the preceding in this circumstance, that the metallic oxide, in combination with the acid, is not separated, but is decomposed: its oxygen, as well as the acid combined with it, are abstracted: it is reduced, therefore, to the metallic form, while the metal effecting this decomposition is dissolved in its place. Thus a slip of copper, immersed in a solution of nitrate of silver, precipitates the silver; or a slip of iron, immersed in a solution of sulphate of copper, precipitates the copper; the precipitating taking the place of the precipitated metal: so that in the former of these cases, nitrate of copper, and in the latter, sulphate of iron, are formed.

In these decompositions different quantities of the metals are requisite to precipitate each other. This was observed by Bergman. In his dissertation on the quantities of phlogiston in metals, he observed, that if 100 parts of silver be dissolved in the requisite quantity of nitric acid, it will require to precipitate it 234 parts of lead, which will be dissolved in its place, 174 of bismuth, 135 of

quicksilver, 88 of tin, 64 of nickel, 31 of copper. From such experiments Lavoisier inferred, that the quantities of oxygen with which the metals combine might be ascertained ; for, as the precipitation of the one metal by the other depends on the transfer of the oxygen, the same quantity of oxygen must have been combined with these different quantities of the different metals. Since 31 parts, for example, of copper, are sufficient to precipitate 100 of silver, it follows, that 31 parts of the former metal can take all the oxygen with which 100 of the latter combine ; and of course, the quantity of oxygen combined with 100 of silver, when it is brought to the state of oxide, is equal to that combined with 31 of copper in the same state. Proceeding on this principle, he prosecuted these experiments *. It is obvious, however, that it is not proved from such results, that each metal is brought to the maximum of oxidizement ; on the contrary, the affinity of the acid may interfere, and determine the combination of each metal in a peculiar stage of oxidizement, different both from the minimum and maximum, and different in each ; and hence the quantities of oxygen with which the metals are disposed to combine, cannot be strictly inferred from them.

These decompositions were ascribed by Lavoisier, or rather by Bergman, (for the speculations of the latter chemist required only a change of terms to adapt them to the modern theory), to the relative forces of affinity of the different metals to oxygen ; those which had a stronger attraction to it precipitating those which had a weaker,

* Mémoires de l'Acad. des Sciences, 1782, p. 512.

the acid being considered merely as the medium, which, by the fluidity or solubility which it communicated, allowed these affinities to operate. And from the series of these decompositions, the order of affinities of the metals to oxygen was even inferred*.

They may in part be owing to this cause; but there can be no doubt that other circumstances interfere and determine them. A clear proof of this, stated by Berthollet†, is, that if we take three metals, suppose iron, copper, and quicksilver, of which the second shall decompose the solution of the third, and precipitate it in its metallic form, and the first decompose, in like manner, the solution of the second; yet this first metal, the iron, in the above example, which decomposes the solution of the second, or the copper, will not decompose, or at least decompose only partially, the solution of the third. But if these decompositions arise merely from the different forces of affinity, the first ought to decompose the solution of the third metal even more readily than that of the second; and the fact, that this does not happen, but that the second, while it is precipitated by the first, precipitates, more readily even than this first, the third metal, affords a proof that they cannot be ascribed to this cause.

The principal modifying circumstance in these decompositions is the affinity of the precipitating to the precipitated metal. Thus the copper, in the above example, precipitates the quicksilver from its solution more readily than the iron does, though the latter has probably a

* Mémoires de l'Acad. des Sciences, 1782, p. 538.

† Researches on Chemical Affinity, p. 123.

stronger attraction than the copper to oxygen, because between the copper and quicksilver there exists a mutual attraction, while there is scarcely any between quicksilver and iron. Hence the metal which is precipitated is seldom, perhaps never, perfectly pure, but has a portion of the precipitating metal combined with it *. It is probable, too, that the different affinities of the acid to the different oxides may influence the results. The participation of oxygen, which, in conformity to the laws of chemical affinity, we might expect to be established between the two metals, appears to be prevented by the much greater tendency to cohesion in the metal in its pure state, than when in the state of an oxide.

When these precipitations take place slowly, the particles of the metal which is separated, unite so as to assume a regular arrangement, or crystallized form. This forms what has been named Metallic Arborescence. According to Mr Sylvester's experiments, galvanic action has a share in the production of this phenomenon; and from this he explains the singular fact, that the ramifications of the precipitated matter increase from their extremities, and of course where they are at a distance from the precipitating metal †. Grotthius had also remarked, that in a metallic solution, subjected to the action of galvanism, the metal is revived at the extremity of the negative wire, and its particles extend from this in a symmetrical arrangement, in the direction of the galvanic current ‡.

* Researches on Chemical Affinity, p. 123.

† Nicholson's Journal, vol. xiv. p. 96.

‡ Philosophical Magazine, vol. xxv. p. 330.

In some cases the decomposition of a metallic salt by another metal is partial, a part only of the oxygen being abstracted ; and the two metallic oxides which are thus formed, are sometimes precipitated in combination.

Inflammable substances, as might be expected from their affinity to oxygen, are capable of effecting similar decompositions of the metallic solutions, and of reproducing the metal in its insulated state. An extensive series of experiments on this subject was performed by Mrs Fulhame *, from which it was established, that such reductions were effected by the agency of phosphorus, sulphur, charcoal, and hydrogen, sulphuretted, and phosphuretted hydrogen, gases. The general manner in which they were executed, was to immerse a piece of silk in the metallic solution, and, while humid, expose it to the action of the phosphorus dissolved in ether, the charcoal dissolved by an alkali, the sulphur in vapour, or the other substances in their elastic state : a change of colour is first induced, and the metal soon appears with all its lustre. A singular fact was established by these experiments, not yet perhaps satisfactorily accounted for, that the presence of water is indispensable to the complete reduction of the metal.

Some of these substances precipitate the metals by being immersed in the metallic solution. This has been long known with regard to phosphorus, and charcoal has the same effect. The decomposition is perhaps principally owing to their superior affinity to oxygen, aided by the cohesion of the metal ; but with regard to phosphorus at least, the same cause appears to operate as in the reduc-

* Essay on Combustion.

tion of one metal by another,—the affinity exerted to the metal which is precipitated. It has been observed, that those metals which have a strong attraction to phosphorus, are more readily precipitated by it than those which have a weak affinity to it, even though the latter may have at the same time a weak affinity to oxygen : thus gold is less speedily and abundantly precipitated than copper *. The phosphorus, too, from the experiments of Schnaubert, appears to combine with at least some of the metals which it thus precipitates, as with silver, quicksilver, and tin †.

Light, as has been already observed, decomposes a number of metallic solutions, either partially de-oxidizing the metal, or reducing some of them to the metallic state. According to Mrs Fulhame's observations, it requires the presence of water, to enable it to act.

The alkalis, it has been stated, in decomposing the metallic salts, sometimes combine with the oxide and the acid, forming a ternary compound. They are also capable of dissolving a number of the metallic oxides in a pure state, or independent of the presence of any acid. Thus the oxides of tin and lead are dissolved by a solution of potassa or soda ; those of copper, zinc, and cobalt, by ammonia. In the dry way, and at an elevated temperature, the fixed alkalis are also capable of combining with a number of the oxides, and with some of them of forming vitrified compounds. It appears even, that the action of an alkali may be so energetic, as sometimes to aid the oxidizement of a metal. Thus tin is oxidized

* Researches on Chemical Affinity, p. 125.

† Nicholson's Journal, vol. viii. p. 138.

at a natural temperature by atmospheric air, when it is acted on at the same time by a solution of potassa.

It has been observed, that the acids, in combining with the metallic oxides, exert stronger affinities towards them when they are in a low, than when in a high state of oxidizement; and hence they favour the disengagement of oxygen from the more perfect oxides. The alkalis appear to observe the opposite law, or have a stronger tendency to combine with the metals in a highly oxidized state. Hence they resist the disengagement of oxygen by heat. This difference is well illustrated in the comparative result of exposing to heat the black oxide of manganese with sulphuric acid, or with potassa: in the first case, much of the oxygen is expelled; which in the second is not, though the heat be more intense.

According to the observation of Klaproth, the solutions of the metallic oxides in the alkalis are decomposed, and the metal is precipitated, in its metallic state, by the action of another metal, which is soluble in the alkali, and which exerts a stronger attraction to the oxygen, in the same manner as the solutions of metals in acids are decomposed. He thus precipitated tungsten, from the solution of its oxide in ammonia, by zinc*.

The metals, either in their pure state or that of oxide, do not form any combination with nitrogen. Hydrogen exerts towards some of them a weak affinity, and is capable of dissolving a small portion of them, as has been observed with regard to iron, zinc, and arsenic.

* Nicholson's Journal, vol. xiii. p. 187.

Carbon, in its pure state, or in that of charcoal, combines with few of the metals, probably from its infusibility in either of these forms. In reducing some of the metallic oxides, however, as those of iron and zinc, by carbonaceous matter, at a high temperature, the metal, in passing to the metallic form, combines with a portion of the carbon; and a still larger quantity can be combined with it, by exposing thin bars of the metal, imbedded in charcoal powder, to a strong heat. By a process of this kind, steel, which is a carburet of iron, is formed.

With sulphur, a number of the metals, all of them indeed except gold and zinc, form combinations by fusion; and a number of metallic sulphurets, as these compounds are named, exist in nature. These combinations retain some of the metallic properties, particularly lustre and opacity, and even a considerable degree of specific gravity. They are destitute of ductility or malleability, and are generally more fusible than the metal of which they consist. They are partially decomposed by heat, the sulphur being expelled.

A striking phenomenon, already taken notice of, occurs when these combinations of sulphur with the metals take place. When the temperature is raised sufficiently high to melt the sulphur, and the union commences, the temperature rises, and a glow of light, similar to that of ignition, and continuing for some time, is produced. This appearance was observed by Scheele *, and afterwards made the subject of experiment by the Associated Dutch

* Treatise on Air and Fire, p. 133.

Chemists *. They exposed to the heat of a charcoal fire, in a close phial, mixtures of sulphur with copper, iron, zinc, and tin, in the proportion of nearly three parts of metal to one of sulphur; this proportion being found, from various trials, to succeed best; and found, that in all of them the luminous appearance took place, soon after the sulphur had passed into a state of fusion, though in different degrees of intensity. That from copper and sulphur, or iron and sulphur, was extremely bright: it was not exhibited by antimony, bismuth, or cobalt. The experiment succeeded perfectly when performed *in vacuo*, or under hydrogen gas, or carbonic acid gas, and even under quicksilver; and likewise when the materials were previously thoroughly dried. The residual matter appeared to be the sulphuret of the metal, without any indication of having received oxygen. The experiment performed with the metallic oxides instead of the metals was attended with no production of heat or light, as Trommsdorff ascertained †.

It was formerly supposed, that the phenomena exhibited in these combinations, afforded an objection against the antiphlogistic theory, as giving an example of the phenomena of combustion without the combination of oxygen; and to obviate this difficulty, some chemists supposed, that the sulphur either itself contained oxygen, or contained water, from which oxygen might be derived. But it is sufficiently obvious, that the extrication of heat and light may attend other chemical combinations as well as those of oxygen; and that this does not disprove the

* Journal des Mines, No. II. p. 85.

† Journal de Physique, 1794, p. 178.

doctrine, that the usual cases of what is considered as combustion,—the burning of sulphur, of phosphorus, &c. are combinations of oxygen with these inflammables.

It has been supposed, that the combinations of sulphur with the metals take place in determinate proportions, and this opinion has in particular been maintained by Proust. He is under the necessity of admitting, however, that an additional and variable quantity of sulphur may be combined with the metallic sulphuret, which is perhaps only a different mode of representing the fact, that the proportions are not determinate *. We accordingly find, that the native sulphurets are very variable in their proportions, as Vauquelin and Klaproth have shown; and the same fact is observed in the compounds which we have it in our power to form †.

The combination of the sulphur with the metals is so intimate, that it is expelled only partially, and in many cases even scarcely at all, by a high temperature. If the air be admitted, however, the sulphur is more completely abstracted, by being converted into sulphurous acid; and by this operation the native sulphurets are decomposed on a large scale, to obtain their metals.

By combination with sulphur, those metals which have a strong attraction to oxygen, as iron, become more susceptible of oxidizement. Hence such sulphurets, exposed to air and humidity, attract oxygen, and pass to the state of sulphate: those which have a weak attraction to oxygen, or a strong attraction to sulphur, do not suffer this

* Journal de Physique, tom. lix. p. 260. Philosophical Magazine, vol. xxi.

† Journal de Physique, tom. lx. p. 349.

change. Muriatic acid, or sulphuric acid somewhat diluted, enables the metal to decompose the water present, and sulphuretted hydrogen is disengaged. Sulphuric acid in its concentrated state, and with the assistance of heat, in acting on these sulphurets, suffers decomposition, its oxygen being shared between its sulphur and the sulphur combined with the metal, it is thus converted into sulphurous acid. Nitric acid oxidizes the metal, and if previously diluted, separates the sulphur; if concentrated, part of the sulphur is also oxidized.

Sulphur is capable of combining with the metallic oxides, forming compounds, which may be named sulphuretted metallic oxides. Such combinations exist in nature: they may also be formed artificially by a moderate heat: if the heat be increased, they are decomposed, the sulphur attracting the greater part, or, perhaps in some cases, the whole of the oxygen, and forming sulphurous acid, while a portion of sulphur remains in combination with the metal. According to the observation of Vauquelin, sulphur has a stronger attraction to the metals than to their oxides, and its affinity to the oxides becomes weaker as they are more highly oxidized*.

Sulphuretted hydrogen acts on the metals and their oxides. It very quickly tarnishes the surface of the metals, and if they are long exposed to it, scales of metallic sulphuret are formed. It combines with the oxides, and sometimes is decomposed by them, reducing them at the same time to the minimum of oxidizement, or even to the metallic state. If its watery solution be added to the

* Nicholson's Journal, 4to, vol. v. p. 318.

solution of a metallic salt, a precipitate is generally formed. This precipitate is sometimes the result of the immediate combination of the sulphuretted hydrogen with the oxide ; but it appears, that in many cases a decomposition, more or less complete, takes place ; the hydrogen of the sulphuretted hydrogen attracting partially, or completely, the oxygen of the metallic oxide, while the sulphur combines with the metal, or with the oxide of the metal at the *minimum* of oxidizement. Those metals, to the oxides of which, in this state of *minimum*, sulphur has no great affinity, are not precipitated from their solutions in acids by the solution of sulphuretted hydrogen, but remain in combination with the acid. Such are iron, manganese, cobalt, and nickel. But when an alkali is present to saturate the acid, they are thrown down, and accordingly, they and the other metals are precipitated by the hydro-sulphurets, and sulphuretted hydro-sulphurets, from similar actions being exerted.

The action of sulphuretted hydrogen on the metallic oxides affords the most delicate test of the presence of a metal. Its solution in water, or its combination with an alkali, precipitates the smallest quantity of a metal in solution ; and as all the metals, except arsenic, are precipitated by a hydro-sulphuret, while none of the earths are, with the exception perhaps of argil, this gives us a very valuable re-agent in analysis. The precipitates, too, thrown down from the different metals, are frequently of peculiar shades of colour, which serve to distinguish them, though they are liable to variation from the state of the combination, and particularly the degree of oxidizement of the metal in the solution.

The alkaline sulphurets are likewise capable of acting with energy on the metals. If the sulphuret of potassa, for example, be exposed to heat with a metal in small pieces, or in filings, a combination is established; and even those metals which cannot be directly combined with sulphur, as gold, can thus be combined with it; a fact long ago observed by Stahl. The reason of this appears to be, as Berthollet has observed, that in attempting to combine gold and sulphur by heat, the affinity not being strong, the cohesion of the gold resists it, and the heat cannot be raised sufficiently high to diminish this, without volatilizing the sulphur, which must be equally an obstacle to the combination. But when the sulphur is combined with a fixed alkali, its volatility is restrained, and the temperature may be raised sufficiently high to combine it with the gold. There is also a singular fact with regard to this combination, that it is soluble in water, the alkali being supposed to hold the metallic sulphuret dissolved; and hence, when an acid is added to the solution, the metal and sulphur are precipitated in combination. It appears doubtful, however, whether the alkali has sufficient energy of action to hold the metallic sulphuret in solution; and there is also some doubt with regard to the nature of the precipitate which an acid throws down. There is still, indeed, considerable obscurity in all that relates to the mutual actions of sulphur and sulphuretted hydrogen with the metals and metallic oxides.

Phosphorus forms combinations with the metals. From the volatility and combustibility of phosphorus, these are not easily effected by exposing the phosphorus and metal to heat, even in close vessels; the phosphorus being part-

ly burnt, and partly sublimed. Margraaf, however, succeeded in obtaining in this way the phosphurets of arsenic, zinc, and copper. The process employed by Pelletier, who made an extensive series of experiments on these combinations, succeeds much better *. It consists in mixing concrete phosphoric acid and charcoal with the metal submitted to experiment, and exposing the mixture to heat: the charcoal attracts the oxygen of the acid; and the phosphorus, as it is reproduced, combines with the metal. The metallic phosphurets have generally a degree of metallic lustre: they are frequently soft, especially if the phosphorus be in large proportion, and, if hard, are brittle: they are more fusible than the metals of which they are formed, and more combustible. They are partially decomposed by heat.

The metals are capable of combining with each other by fusion. To these combinations, the name of Alloy is given in the new nomenclature; as the alloy of gold and silver, of lead and tin, &c. They all retain the general metallic properties,—lustre, opacity, and density; and even in the greater number of cases, the properties of the constituent metals remain in the combination, only somewhat modified. In general, they are more hard and brittle than the individual metals of which they consist, though this, as well as the other changes of properties, are considerably influenced by the proportions in which the ingredients are combined †. They have also in general a greater fusibility than the mean fusibility of the re-

* *Mémoires de Chimie*, tom. i. p. 212. and ii. p. 22.

† *Chemical Statics*, vol. ii. p. 301.

spective metals. The alloys of quicksilver are soft, or liquid, according to the proportions. The metals in these combinations are more susceptible of oxidizement than in their separate state, probably owing to the diminution in the power of cohesion by the combination. From their peculiar properties, some of the alloys are extensively used, as brass, which is an alloy of copper and zinc, and pewter, an alloy of tin and zinc.

A degree of condensation usually attends these combinations, so that the specific gravity of the alloy is greater than the mean specific gravity of its constituent metals: in brass, for example, it is one-tenth greater; and in some cases, the condensation is such, that the density is even greater than that of the heavier of the metals combined, as in the alloy of silver and quicksilver. Sometimes, however, the particles assume such an arrangement, that the density is less than the mean, as in the examples of the alloy of copper with silver, and of gold with tin, and gold with iron.

In these combinations, there exists a certain order of attractions, by which one metal is more disposed to unite with another than a third is. The difference, however, is not very considerable: hence three, four, or more metals can be combined together. Some, however, refuse to unite, as iron and lead, and iron and quicksilver. The combination seems to be in some measure regulated by the relation of fusibility and specific gravity; so that the affinities being equal, the metals are less disposed to combine, as they differ more in their fusibility and specific gravity; and where the affinity is weak, a considerable difference of this kind may prevent any combination whatever.

The same cause appears often to place limits to the combination, or to regulate the proportions in which it takes place. The mutual attraction would effect the combination in every proportion ; and, accordingly, with regard to many metals this happens ; but with regard to others, particular proportions, or at least a certain limit to the combination, may be discovered. The influence of the specific gravity, in thus determining proportions, is clearly established by a fact, known to the older chemists, observed by Bergman, in the alloy of iron and tin, and by Guyton in the alloys of silver and lead, and silver and iron, that the upper and under parts of a metallic alloy formed by fusion, frequently differ in the proportions of its parts, the under portion containing more of the heavier metal, the upper more of the lighter. When a large quantity of one metal, however, is melted with a small quantity of another, the combination is generally uniform ; the quantity adding so much to the force of affinity, as to overcome any counteracting property, while, if other proportions are observed, two separate alloys, with different proportions, one containing a large quantity of one metal, and the other a large quantity of the other, will be obtained *.

The art of soldering depends on the formation of an alloy ; the solder being a metallic compound of greater fusibility than the metal or metals designed to be united, and probably serving also by its affinity to them to unite them more firmly. The arts of gilding, silvering, and tinning, depend also on the mutual affinities which the metals exert.

* Researches on Chemical Affinity, p. 75.

The metals exert no attractions to the earths. The metallic oxides, however, are capable of uniting with several of the earths by fusion: they even render them more fusible, and form glasses which have often brilliant colours. They are thus used in the formation of the pastes, as they are named, which imitate the gems.

The metals are found in nature in various states. When uncombined, or when combined only with each other, they are said to be in a native state. When combined with other substances, so that the metallic properties are in some measure disguised, they are said to be mineralized, or in the state of ore. The substance with which the metal is combined, is termed its Mineralizer. The most common states of combination in which the metallic ores are found, are oxides, combinations of oxides with carbonic, sulphuric, muriatic, and phosphoric acids, and sulphurets. These ores occur under various forms, sometimes crystallized, and often destitute of any regular figure. They are met with generally in veins penetrating the strata; and in this case, are usually blended or intermixed with various earthy fossils, as calcareous spar, fluor spar, quartz, &c. The accompanying fossil was formerly, from an absurd notion, termed the matrix of the metal. Some metallic ores occur in beds, or in large insulated masses.

To obtain the metal after it has been extracted from the vein, various operations are requisite. The ore must be separated from the accompanying earthy fossils, which is done as much as possible by the hammer. Where the ore, and the matter which forms the matrix, are more intimately mixed, advantage is taken of the difference in their specific gravity. The whole, after being coarsely

pounded, is washed with water on an inclined plane; the water carries off the earthy substances, and the metallic matter remains behind. After this operation, the ore, if it contain sulphur or arsenic, or any acid, is subjected to a low red heat, which is termed roasting it, and by which any of these substances is expelled. It is lastly necessary to reduce the metal, or to separate the oxygen with which the metal has either been naturally combined, or has united during the operation of roasting. This is done, by placing in a furnace alternate layers of coal, or, still better, charcoal, and the metallic matter: a strong heat is excited by bellows: the carbonaceous matter attracts the oxygen; and the metal is reduced, melted, and run out at the bottom of the furnace. The volatile metals are obtained by sublimation or distillation. Even after these operations, the metal is seldom pure, but is combined with other metals, which have been present in the ore. If these are in small quantity, and do not injure the metal, they are in general disregarded. If it is necessary, however, to separate them, or if, from their value, it becomes an object of importance, different processes are followed, adapted to each, which will require to be noticed under the different metals.

The art of assaying metallic ores, is that of analysing them in small quantities, so as to discover their component parts. It requires a perfect knowledge of the relations of the metals to the other chemical agents, and is varied in its different stages as applied to each. The general process consists in selecting properly specimens of the ore, which is done by taking equal portions of that which appears to be the richest, the poorest, and of me-

dium value, and reducing these to coarse powder, which is washed to carry off any earthy or stoney matter : it is then roasted in a shallow earthen vessel under a muffle, to expel the volatile principles : it is lastly reduced by mixing it with three times its weight of black flux, and exposing it to the requisite heat ; using other fluxes, and applying a more or less intense heat, as the metal is more or less refractory. The metallic matter existing in the ore is thus obtained. This, it is obvious, may consist of various metals ; and if there is reason to believe this, and it be of importance to ascertain it, it is submitted to operations generally conducted in the humid way, and adapted to the metals which may be supposed present. Sometimes also an accurate analysis is made at once of the metallic ore in the humid way ; the metal being dissolved by the different acids, and precipitated by the alkalis, earths, prussiate of potassa, by sulphuretted hydrogen, and other re-agents. The minute details of the process, as applied to the different ores, which are inadmissible in this place, were given by Bergman ; and many improvements have been since introduced by Klaproth, Vauquelin, and other analysts, to whose works it is necessary to refer *.

Besides being found in the earth, several of the metals are constituent principles of organized matter. Iron is contained in considerable quantity in the blood, and in some other animal products, and it, as well as gold and manganese, can be extracted from the ashes of vegetables.

* Bergman's Essays, vol. ii. p. 406.

Klaproth's Analytical Essays.

The class of metals has been subdivided into several orders, under which the individual metals are arranged. Gold, silver, and platina, preserving their lustre on exposure to the air, possessing a high degree of ductility and malleability, and not being oxidized, when exposed even to a very strong heat, have been placed in one order, under the appellation of Perfect or Noble Metals. Quicksilver, copper, iron, tin, and lead, possessing ductility and malleability, but being oxidized by heat, have been placed together under the name of Imperfect Metals. The others, zinc, antimony, bismuth, cobalt, nickel, manganese, arsenic, (and the greater number of the newly discovered metals may be added to this order), having little ductility or malleability, were termed Semi-Metals. This was the old division: others have been introduced, as that of Fourcroy, who arranges them partly from their physical, partly from their chemical properties; or that of Haüy, who arranges them from their relation to oxygen, placing in one order those which are not capable of combining with oxygen by being heated with atmospheric air, and the oxides of which are reduced by heat alone; under another, one metal, quicksilver, the characters of which are, that it suffers oxidizement when heated, and at the same time, at a higher temperature, its oxide is reduced; and under a third order, all those which are oxidized by atmospheric air at a high temperature, but the oxides of which are not reducible by heat alone.

Any classification of this kind is inaccurate, and without utility. No advantage is gained by forming such orders, and they are altogether artificial: each metal forms a species, and they may be considered individually in that

order in which the transition is most natural, beginning with those which have the characteristic metallic properties, tenacity and specific gravity, in the highest degree.

There is reason to suspect, that among the bodies arranged as metals, there are some which are alloys. This suspicion applies more particularly to those which are found in sparing quantity in nature, and which are not distinguishable by very characteristic properties, but only by shades of difference extremely minute. Differences much greater exist between many metallic alloys and the metals of which they are composed ; and there are several alloys, the component parts of which it is scarcely possible to separate, so that if we had not actually formed them,—if we had met with them in nature, we should not have been able to discover their composition by analysis, but have been led to regard them as simple metals.

This evidently confirms the probability, that some of those substances, placed as distinct metals, may merely be undiscovered alloys. This conjecture will of course apply principally to those metals which are found as it were insulated, which are discovered merely perhaps in a particular fossil, and which, at the same time, have no very distinctive character, nor any very marked chemical action. It is a just observation by Mr Chenevix, that metallic alloys are in general brittle compared with the metals of which they are formed ; and it is therefore among the brittle metals, or what have been named the semi-metals, that we may expect the simplification of the class.

CHAP. I.

GOLD.

GOLD has always held the first rank among the metals, from its great ductility, malleability, specific gravity, and the richness of its colour and lustre, which are not impaired by the action of air or humidity. A metal of modern discovery, platina, is superior to it in specific gravity : the difference, however, is inconsiderable : it is inferior, too, in some of the other characteristic metallic qualities ; and as platina is more allied in its general qualities with silver, it may follow or precede that metal, and the first place be still allowed to gold.

Gold is found in a native state, either pure, or alloyed, more or less, with other metals, particularly with silver, copper, and tellurium. It is sometimes also contained in other metallic ores, particularly in some varieties of pyrites, in which it is supposed to be mechanically disseminated. It also appears to exist in the vegetable kingdom ; the experiments of Rouelle, Sage, and other chemists, having proved that it can be extracted in small quantity from the ashes of plants.

The extraction of native gold from the foreign matters with which it has been naturally mixed, is performed by

amalgamation with quicksilver. After having been freed, by pounding and washing with a stream of water on an inclined plane, from the stoney matter mixed with it, it is triturated with ten times its weight of quicksilver: the amalgam, separated from any superfluous earthy matter, is subjected to pressure in leather, by which the more fluid part is separated and forced through the leather, while the more consistent amalgam, containing the greater part of the gold, remains. It is subjected to distillation in retorts of earthen ware to separate the quicksilver, and the remaining gold is afterwards fused. When the gold is contained in other ores, the ore is roasted to volatilize the more volatile principles, and to oxidize the other metals: the gold is extracted by amalgamation, by liquefaction with lead, by the action of nitric acid, or other methods adapted to each ore according to its constituent parts.

Gold obtained in any of these ways, is more or less alloyed, particularly with silver and copper. The first step in its purification is the process of Cupellation. To explain the nature of this, it is necessary to observe, that lead is a metal very fusible, extremely easy of oxidizement, forming an oxide which easily vitrifies, and which favours the oxidizement and vitrification of other metals. A portion of lead, therefore, is added to the impure gold, more or less according to the quantity of alloy it contains, which the workman judges of by the colour, hardness, elasticity, and specific gravity of the gold. They are melted together, and exposed to heat on a cupel (which is a vessel made of bone ashes, or sometimes of wood ashes) under a muffle, or, in the large way, on the hearth of the refining furnace. The lead passes to the state of oxide,

is vitrified, and promotes the oxidizement and vitrification of the foreign metals. The vitrified oxide is absorbed by the porous cupel, or, in the large way, the greater part is driven off by the blast of bellows, and removed. When the greater part of the foreign metals are abstracted, the remaining fused metal exhibits various prismatic colours, which succeed each other quickly : it at length suddenly brightens, or its surface becomes highly luminous. This is regarded as the completion of the process : the metal is allowed to become solid, and while yet hot is detached. The whole operation requires much practical skill, particularly with regard to regulating the heat properly in the different stages.

The gold, even after having been submitted to this process, may still be alloyed with silver, which, being nearly as difficult of oxidizement, is not removed by the action of the lead. It is therefore lastly subjected to the operation of Parting. The metal is rolled thin, and cut into small pieces : these are digested with a moderate heat in diluted nitric acid, which dissolves the silver, leaving the gold undissolved in a porous mass. It has been found, however, that when the proportion of silver is small to that of gold, the latter protects the former from the action of the acid : the previous step of Quartation, as it is named, is therefore employed, consisting in fusing three parts of silver with one of the gold, and subjecting this alloyed metal to the operation of the acid. These are the operations employed in commerce. To obtain gold perfectly pure, still another process is perhaps necessary,—dissolving it in nitro-muriatic acid, and adding to the solution a solution of sulphate of iron, which attracting the oxygen, precipitates the gold in the metallic state.

There is a peculiar language established in commerce, and often referred to by chemical authors, to denote the purity of gold, or the degree of its alloy with other metals. The mass is supposed to consist of 24 equal parts ; these imaginary parts being named Carats. If perfectly pure or unalloyed, it is said to be gold 24 carats fine : if alloyed with one part of any other metal, or mixture of metals, it is said to be 23 carats fine. In this way the proportion of alloy is expressed.

Gold, when perfectly pure, is of a rich yellow colour, inclining to red : its lustre, which is considerable, and scarcely inferior to that of any other metal, is not impaired by exposure for any length of time to air or moisture ; its specific gravity is 19.25, and when hammered 19.36 ; it is inferior only to that of platina. In malleability it is superior to all the metals : in the finest gold leaf, it is calculated by Magellan, from the weight of a known number of the leaves of a measured surface, that one grain of gold is extended to above 56 square inches. It suffers even a greater extension than this in the gilding of silver wire. The cylinder of silver, after having its surface coated with the gold, may be drawn into wire so fine, that one grain of gold covers a length of 294 feet, and covers it so perfectly that no part of the silver beneath is visible. Its ductility is also very great, so that it can be drawn into very fine wire. In hardness, it is inferior to iron, platina, copper, and silver : it can be easily cut with a knife.

Gold melts at 32° of Wedgwood's scale. When in fusion, its colour is a brilliant sea-green. It crystallizes by slow cooling in minute octaedrons. By the intense

heat of the solar rays in the focus of a powerful lens, it is volatilized. This was proved by an experiment of Macquer, in which the vapour of the gold was condensed on a plate of polished silver held above the gold in the focus of the mirror ; and Lavoisier also found it to be volatilized by the heat excited by a stream of oxygen gas directed on burning charcoal.

It was formerly supposed, that gold is incapable of oxidizement by the action of heat and air. The older chemists, as Boyle and Kunckel, kept it exposed for months in a state of fusion to a very violent heat, without finding it to undergo any change ; and as its oxide, when obtained by the agency of an acid, is reduced to the metallic state, by a heat not much exceeding that of ignition, it has been inferred, that this precludes the possibility of the metal attracting oxygen, in its elastic state, at a high temperature. This has even been maintained by Berthollet, who has remarked, from this fact of the decomposition of the oxide by the action of heat, that “ it cannot be supposed that this action, by being rendered more energetic, can produce an effect totally opposite *.” In some experiments which were made by Macquer and others, and in which gold appeared to be oxidized when exposed on vessels of earthen ware to the heat of powerful burning-glasses, he supposes the effect to have been produced by the action of the earthy matter, which, by a species of disposing affinity, promoted the oxidizement, and the consequent vitrification of the oxide.

On this subject, however, there is now no ambiguity ;

* Chemical Statics, vol. ii. p. 311.

and the possibility of oxidizing gold at a high temperature cannot be disputed. Gold leaf, inclosed between plates of glass, and subjected to a powerful electric discharge, is converted into a purple oxide. Van Marum caused it to burn by very powerful electric sparks; and Mr Cuthbertson has also shewn, by an experiment liable to no source of error from the operation of any foreign substance, that electric discharges, transmitted over a gold wire inclosed in a glass tube with atmospheric air, convert it into an impalpable powder of a dark brownish purple colour, while the air is at the same time diminished in volume, and rendered incapable of supporting combustion *. The combustion of gold is even vivid, accompanied with a yellow light, when it is subjected to the action of a powerful galvanic battery; and it burns in the flame of an united stream of oxygen and hydrogen gases. In these cases, an intense heat suddenly applied to the metal, probably volatilizes it, and thus enables it to combine with oxygen, the oxide at the same time being withdrawn from the high temperature; while a lower heat, gradually applied, would augment the elasticity of the oxygen gas, without proportionally diminishing the cohesion of the metal.

In conformity to the opinion of the difficult oxidizement of gold, it was supposed not to be effected by deflagration with nitre: and this process has been employed to free it from the baser metals with which it has been alloyed. From the experiments, however, of Mr Tennant, it appears, that this opinion is not just. In exposing the diamond to the action of nitre at a high heat in a gold tube,

* Nicholson's Journal, vol. v. 4to, p. 146.

he observed that part of the gold was dissolved ; and on exposing gold with nitre to a red heat for three hours, a portion was dissolved : on adding water to dissolve the saline matter, part of it was precipitated in the metallic state ; but a portion, about 1-6th, apparently in an oxidized state, remained in solution, which was afterwards precipitated by sulphuric or nitric acid *.

The purple oxide of gold, in which the metal appears to be at the minimum of oxidizement, has been supposed to contain about five or six parts of oxygen in 100. By precipitation from some of its saline combinations, a yellow oxide may be obtained, in which the proportion of oxygen is supposed to be greater, and to amount to about 10 parts. Both these oxides are decomposed, and the oxygen completely expelled, by an elevation of temperature not much superior to that of ignition.

The attraction of gold to oxygen is so weak, that it is scarcely affected by the greater number of the acids. It was formerly supposed to be perfectly insoluble even in the nitric or nitrous acid, which, in general, parts with oxygen with so much facility ; and when gold leaf is put into the acid in the cold, it seems to suffer no change. Some experiments, however, appear to prove, that when nitric, or rather nitrous acid, is boiled on gold, it is capable of dissolving a small portion of it. This was first observed by Brandt, a Swedish chemist, and was confirmed by Schoeffer and Bergman. It was afterwards made the subject of experiment by Tillet, who found, that by boiling nitrous acid on gold for a considerable time, the

* Philosophical Transactions, 1797.

metal lost weight, which, however, he laboured, in opposition even to the facts his experiments establish, to prove, is owing to the erosion and mechanical suspension of the gold, and not to its proper solution *. According to Deyeux, the gold is more readily dissolved, when the acid is highly charged with nitric oxide; and, as Fourcroy remarks, the solution succeeds on this account best in the cold. It is decomposed by the action either of heat or light, which separates the gold in shining particles. The quantity dissolved is so inconsiderable, and depends on such conditions, that the accuracy of the processes of assaying can scarcely be affected by it.

The proper solvent of gold is the nitro-muriatic acid, named from this property by the alchemists *Aqua Regia*; gold, in their language, being the king of metals. The acid generally used, is that formed of two parts of nitric acid, and one of muriatic acid. Gold leaf put into it instantly disappears; and when poured on gold in mass, the solution is accompanied with an effervescence, from the disengagement of nitric oxide gas. There is reason to believe, that the above proportion of nitric acid is too great: it has, accordingly, often been reduced to equal parts. And from the experiments of Proust, in his history of gold †, it appears, even that an acid, formed of four parts of muriatic acid to one of nitric, dissolves more gold than where a less proportion of the former acid is used. As gold is soluble in oxy-muriatic acid, and as a portion of this acid is formed by the reciprocal action

* *Mémoires de l' Acad. des Sciences*, 1780, p. 241.

† *Nicholson's Journal*, vol. xiv. p. 238.

of nitric and muriatic acids, it has been supposed, that its solution in the nitro-muriatic depends on the presence of the oxy-muriatic acid. As it is dissolved, however, more rapidly, and in larger quantity, than it is by oxy-muriatic acid in any state of condensation, it is probable, as Berthollet has suggested, that its solution depends on the muriatic acid exerting a disposing affinity, enabling it to decompose the nitric acid present, so as to receive oxygen, the muriatic acid combining with the oxide; the operation being similar to that by which an acid facilitates the oxidizement and subsequent solution of a metal, by enabling it to decompose water. Muriatic acid must exert such an affinity; and it appears from the facts above stated, with regard to the action of nitric acid on gold, that the addition of a weak force will enable the gold to decompose that acid with rapidity. Accordingly, the combination is principally a muriate of gold, as the oxidizement of the metal can proceed only while the affinity of the muriatic acid aids it; and when this is satisfied, it must cease, though a portion of undecomposed nitric acid may be present. For the same reason it is difficult, or perhaps impracticable, to obtain a solution without an excess of acid. Strictly speaking, too, the solution is a nitro-muriate, or the nitric acid present no doubt exerts an action on the metallic oxide, as well as the muriatic acid; and it is only by evaporation and crystallization, when the force of cohesion operates, that the proper muriate of gold is obtained.

The solution, when the compound acid has dissolved as much of the gold as it can do, is of a rich yellow colour; it is extremely corrosive, and communicates to ani-

mal membrane a purple tinge. By evaporation, crystals of muriate of gold are obtained of a rich yellow colour, and in the form of single or double tetrahedral pyramids. This salt is very deliquescent : it is easily soluble in water, and also in alcohol and ether : it is decomposed by heat, which expels part of its acid, and by light, which separates its oxygen.

A similar combination is formed by the action of oxy-muriatic acid on gold ; the oxygen of this acid being retained even by a weaker affinity than in the nitric acid, the gold attracts it, and combines with the muriatic acid. The solution, however, is slow, and no large quantity of gold can be dissolved, partly from oxy-muriatic acid not being in a very concentrated state, and partly perhaps from the quantity of oxygen present not being such as to form a sufficient quantity of oxide to saturate the acid. In oxy-muriatic acid gas, gold leaf is instantly fused with inflammation, and dissolved.

Although gold cannot be dissolved by the other acids when in its metallic state, its oxides may be combined with them, and an extensive series of salts formed. None of these, however, have been examined with any attention. According to Gren, the sulphate and nitrate do not crystallize. The phosphate may be fused, and forms a glass of a fine red colour.

The solution of gold in nitro-muriatic acid is decomposed by the alkalis, which at the same time give rise to some particular phenomena from their re-action on the oxide. Potassa throws down a precipitate of a yellow colour, which varies according to the state of the solution with regard to dilution, and the quantity of alkali

used. It is not easy to precipitate the whole of the gold; and if an excess of alkali be added, part of the precipitate is redissolved. Proust has remarked, that part of the gold is precipitated in its metallic state, and that this may be discovered, by adding muriatic acid to the precipitate, which dissolves the oxide, leaving the metallic gold undissolved *. The action of soda, so far as it has been observed, is similar. The precipitates which both alkalis give, are decomposed by heat, and the gold reproduced. They are soluble in nitric and sulphuric acids, forming solutions which do not easily crystallize.

The action of ammonia on muriate of gold is still more singular, affording a precipitate which is highly fulminating, and which, being one of the first chemical preparations possessing this property known to chemists, has, of course, much engaged their attention. It was known even to the alchemists. Bergman ascertained the principal facts with regard to its production and composition: and Berthollet gave the theory of its detonation.

To a solution of gold in nitro-muriatic acid, diluted with three or four times its weight of water, liquid ammonia is added, as long as any precipitate is thrown down, taking care not to add an excess of alkali, by which part of the precipitate would be redissolved. The clear liquor being poured off, the precipitate, after being washed with water, is allowed to dry by exposure to the air, avoiding the application of heat. It is of a reddish yellow colour, and weighs about one-fourth more than the gold employed. This forms what has been named Aurum

* Nicholson's Journal, vol. xv. p. 243.

Fulminans, Fulminating Gold. A similar preparation may be obtained by dissolving gold in a nitro-muriatic acid, which has been prepared by adding muriate of ammonia to nitric acid, and decomposing the solution by potassa; or by precipitating the oxide of gold from its solution by a fixed alkali, and afterwards digesting it in ammonia.

Its detonation is occasioned by heat, or by friction, or percussion. The temperature that is requisite, is, according to Bergman's observation, between 120° and 300° : it explodes with an acute report, and an obscure flash: if exploded on a metallic plate in the quantity of 10 or 12 grains, it generally perforates or lacerates it: in smaller quantity it depresses it. By friction in a mortar, or even by a slighter agitation, its explosion is also occasioned. Though the accounts of the older chemists with regard to its detonation are exaggerated, it has frequently been the cause of unfortunate accidents. One occurred in the presence of Macquer: A person having put a quantity of it into a phial with a glass-stopper, and not observing that a small quantity had adhered to the neck of the phial, on turning round the stopper, caused this to explode: the explosion was probably communicated to the remaining quantity in the phial, as the person was thrown to a distance with violence, and rendered blind, by the minute splinters of glass having struck both eyes.

The detonating power is much lessened by interposing between the particles of the fulminating gold any unflammable matter, as by mixing with it a little of either of the fixed alkalis, or the earths. Sulphur entirely removes it, so that the mixture burns merely with a slight deflagration. Oils have the same power. The acids, at least the

diluted sulphuric and the nitric, do not decompose it even with the assistance of heat, as it still continues to detonate as before : nor does water boiled on it remove any of its principles, or impair its detonating power. Muria-tic acid, however, dissolves a portion of the oxide of gold, and thus alters the composition.

Notwithstanding the risk which attends experiments upon it, a number have been made with the view of discovering the cause of the detonating quality. By exploding small portions of it in close glass-vessels, a powder of a purple colour is obtained, with which are intermixed many particles of reduced gold : and if the experiment be performed so as to collect any aërial product, an elastic fluid is disengaged, which, as Bergman found, extinguishes flame, proves fatal to life, is not absorbed by water, and gives no precipitation with lime-water. He observed also, that by heating it very gradually, it suffered decomposition without detonation, as it did also when heat was applied to it under pressure, as in close metallic vessels : And farther, that the use of ammonia in the preparation is absolutely necessary, and that a portion of it is contained in the fulminating gold : or that this is a compound of ammonia and oxide of gold *. In its formation, therefore, one portion of the ammonia must saturate the acid ; and the oxide of gold, thus separated from its combination, must attract another portion of the ammonia, forming with it an insoluble precipitate. Its detonation Bergman ascribed to the re-action of its immediate principles at a high temperature, and the consequent disengagement of

* Physical and Chemical Essays, vol. ii. p. 134.

elastic products, though, from the composition of ammonia not being fully known, the explanation was somewhat deficient in precision. When ammonia was proved to be a compound of hydrogen and nitrogen, it became obvious, as Berthollet remarked, that the oxygen of the oxide of gold attracts the hydrogen of the ammonia, forming watery vapour; the nitrogen at the same time assumes the elastic form, and the elasticity of both being augmented by the high temperature, gives rise to the detonation: and accordingly, by detonating it in a copper tube, Berthollet found nitrogen gas to be disengaged; a few drops of water condensed at the extremity of the tube; and the gold reduced to the metallic state. These new combinations take place with rapidity, either from the application of heat or friction, principally from the weak affinity with which oxygen is retained by gold. Gren supposed that the fulminating gold contains muriatic acid; that when heated, this attracts the oxygen of the oxide, passes to the state of oxy-muriatic, or perhaps hyper-oxy-muriatic acid, which re-acts on the ammonia;—an hypothesis not improbable, from the consideration that metallic precipitates not only attract part of the precipitating substance, but frequently retain also a portion of the acid with which the metallic oxide had been combined.

The muriate of gold is decomposed by a number of agents, which expel or attract its oxygen. It is thus reduced to the metallic state by the chemical agency of light, of hydrogen, and of a number of inflammable bodies, as is well exemplified in the experiments of Mrs Fulhame already referred to. A piece of silk dipt in a dilute solution of it, moistened with water, and exposed to the rays

of the sun, is soon covered with reduced gold ; and a similar appearance, more or less perfect, is produced by exposing the silk to hydrogen gas, to sulphurous acid gas, to a solution of phosphorus in ether, or to an alkaline solution of charcoal. Phosphorus immersed in the solution of muriate of gold, precipitates the metal.

The greater number of the metals likewise decompose it. Copper, iron, and zinc, throw down the gold in its metallic state ; other metals, as silver, or lead, in the state of the purple oxide. A precipitate of this kind by tin, is valued for the beauty of the colour it gives to glass or enamel. This, known to the artists by the name of Purple Powder of Cassius, may be obtained by various processes, and even simply by immersing a plate of tin in a dilute solution of muriate of gold ; but that generally followed when it is prepared for the above use, is to dissolve pure gold in nitro-muriatic acid. A solution of tin is likewise prepared, by dissolving the metal in small portions at a time, without the application of heat, in an acid composed of two parts of nitric, and one of muriatic acid, previously diluted with an equal weight of water. This solution, after it has attained saturation, is largely diluted ; and to this the solution of gold, in quantity equal to half the quantity of solution of tin, is added : the liquor becomes of a beautiful purplish red colour, and a precipitate of this colour subsides, which is to be washed and dried. It is the only known preparation which gives a red colour to glass. When properly prepared, the colour it does give is extremely beautiful, and the glass prepared with it serves as an imitation of the ruby.

The theory of this preparation was not understood un-

til elucidated by the researches of Pelletier, and it was found even extremely difficult to conduct the process with uniformity; the colour of the precipitate being extremely various, from circumstances not easily appreciated. This chemist shewed that it is a compound of oxides of tin and gold, and that its formation is owing to the strong attraction of the tin to oxygen, and the large quantity of that principle with which it is disposed to combine. When the two solutions are mixed, the oxide of tin, which is nearly at the minimum of oxidizement, attracts part of the oxygen of the oxide of gold: the two oxides, thus brought to states of oxidizement different from those in which they existed in the separate solutions, and probably likewise exerting mutual affinities, are no longer soluble, and are precipitated in combination. This theory also points out the circumstances required to be attended to in the process to obtain the preparation uniform: the whole depends on having the solution of tin at the *minimum* of oxidizement, or as nearly so as possible; and hence it must be prepared slowly, without the application of heat, and must be used newly prepared, as otherwise the tin passes to too highly an oxidated state. Proust has maintained, with little probability, that the gold exists in this preparation in the metallic state, united with the oxide of tin.

Muriate of gold is decomposed by some other metallic salts, in consequence of similar actions; the oxygen of the oxide of gold being attracted by the oxide of the other metal, which hence passes to a higher state of oxidizement. Those which have a great tendency to exist in such a state, are capable even of completely de-oxid-

izing the oxide of gold. Thus, if a solution of the green sulphate of iron be added to the solution of muriate of gold, the gold is precipitated in minute particles in the metallic state, while the iron passes to the state of the red sulphate. From the purplish colour which the precipitate has, it probably contains a portion of oxide; and according to Proust, either muriatic or nitric acid dissolves a little of it, which must be regarded as a proof of this oxidized state. This has been regarded as the best re-agent to discover gold, and also as affording the best process for obtaining gold pure; but it has been affirmed by Mr Keir, that silver is precipitated in a similar manner, so that if the gold be alloyed with it, it will not be separated.

Muriate of gold is gradually decomposed by ether, or by volatile oils. On mixing these with its solution, the muriate is at first dissolved and separated from the watery part. This solution is even soluble in alcohol, and such liquids formed the different kinds of what was formerly named Potable Gold. On standing, the gold is gradually precipitated in its metallic state; the oxygen combined with it in the muriate, being attracted by the carbon, or perhaps the hydrogen of the ether or oil.

The alkaline hydro-sulphurets, or sulphuretted hydro-sulphurets, throw down a precipitate from muriate of gold of a yellow colour. The precipitate by sulphuretted hydrogen, is, according to Proust, a mixture of sulphur and gold.

Gold does not combine with sulphur by fusion, and on this is founded a method of freeing it from silver or other metals, the alloy being fused with sulphur, or sometimes with sulphuret of antimony, and the sulphur uniting with

the foreign metals. Gold and sulphur unite, however, by the medium of an alkali. If sulphuret of potassa is fused in a crucible with one-eighth of its weight in gold leaf, a combination is formed, which is completely soluble in water, the solution being of a green colour. It is decomposed by acids : it is uncertain, whether, in the precipitate which is thrown down, the sulphur is in combination with the gold in its metallic or in an oxidized state.

Gold combines with phosphorus, either by the process of Pelletier, already described, (p. 50.), or by projecting small pieces of phosphorus on the melted gold. The compound is of a white colour, and brittle, though it appears to contain only a small proportion of phosphorus, according to Pelletier, not more than about a twenty-fourth of its weight. It is also more fusible : when heated in atmospheric air it is decomposed, the phosphorus burning at its surface.

Gold forms alloys with the greater number of the metals. An extensive and accurate series of experiments on these alloys was made by Mr Hatchet, with the view of determining the principal facts with regard to the use of gold as coin *, of which it will be sufficient here to give a brief abstract ; as any of them, which has properties sufficient to entitle it to notice, will be better introduced under the history of the other metals.

All the metals, with the exception of silver, platina, and copper, in combining with gold, very much impair its ductility or its colour. Bismuth, lead, and antimony, are those which render it most brittle. The alloy with pla-

* Philosophical Transactions, 1803.

tina is of a yellowish white colour, very ductile, and having considerable specific gravity : it is also considerably elastic when hammered. The alloy with silver in the standard proportion, or 1 in 12, approaches the nearest to the ductility of fine gold of any alloy, and its specific gravity differs little from the mean specific gravity of the respective metals. When the silver amounts to one-fifth, the colour of the alloy approaches to green, and forms the green gold of the goldsmiths. Gold, in combining with copper, has its colour rather heightened than impaired : its hardness is increased, and its ductility very little lessened, when the standard proportion of 1 part in 12 is not exceeded. Hence this alloy of 22 carats fine, is generally used when gold is fabricated into plate or ornaments, and also forms the gold coin of this country. From Mr Hatchet's experiments, however, it appears, that a very small portion either of lead or antimony in the copper, impairs very much the ductility of the alloy ; and as both these metals are frequently associated with copper in its ores, and are to be discovered in the copper of commerce, the brittleness which is often communicated to gold by copper must arise from their operation. One ounce of copper he found might contain four grains either of antimony or lead, without any apparent change of colour or ductility ; but if such copper were used to alloy gold, one ounce of it being added to eleven ounces, there would be considerably more lead or antimony present than is sufficient to destroy the ductility. With quicksilver, gold unites with great facility. If the surface of the gold be merely touched with it, it immediately becomes white ; its substance is soon penetrated so as to become quite

brittle, and in no long time it is completely dissolved. The amalgam is of a yellow colour, and, if the proportion of gold be large, is solid and crystallizable. If heated in atmospheric air, both metals are oxidized. The alloy with iron is much harder than gold, very ductile and malleable; but the colour is debased to a yellowish grey, approaching to a dull white. Tin, by the older chemists, was supposed, even in the most minute quantity, to render gold extremely brittle. This was shewn to be a mistake by Mr Alchorne, and must have arisen from tin so frequently containing antimony, lead, bismuth, or zinc. A large proportion, as 1-10th, impairs the ductility, and renders the colour pale; but a small quantity, as 1-30th, does no material injury: it is more brittle at a high temperature. Zinc is injurious to the ductility of gold: the alloy is decomposed by heat, part of the zinc being volatilized. Lead, bismuth, and antimony, even in very small quantity, render gold very brittle; less than one quarter of a grain to an ounce having this effect, and diminishing likewise the colour and brilliancy. Even the vapour arising from these metals in fusion, produces these changes. The colour and ductility are less injured by nickel than by any of the other brittle metals. Cobalt is more injurious, as are also manganese and arsenic. The alloy with manganese is less fusible than pure gold: that with arsenic is very fusible, hard, and of a grey colour. In all these combinations the volatility of the more volatile metals is impaired, and the oxidizement of the more oxidizable metals takes place with much less facility, and is probably not complete.

Gold is applied to many useful and ornamental pur-

poses. It is used among civilized nations, as the principal medium of exchange. When perfectly pure, however, it is not so fit for coin, from its softness ; in consequence of which the impression is soon obliterated, and it sustains loss from friction ; hence it is always alloyed, to give it hardness. The metals that have been used for this purpose, are silver or copper. The alloy with the former is very ductile, but it is scarcely sufficiently hard, and the colour is too pale. That with copper is of a much deeper colour, and is harder ; while it is sufficiently ductile, if the copper has been pure. Gold made standard by a mixture of equal parts of silver and copper, has a colour approaching more to that of pure gold than any other alloy : this colour also remains uniform, while that of copper, after a certain degree of wear, becomes unequal *. This alloy appears also to suffer less from friction ; but though it has these advantages, it does not appear, from Mr Hatcher's inquiries, that they are sufficient to compensate for the additional expence of the silver, especially as the gold brought to the mint generally contains a little

* The cause of this is explained by Mr Hatcher. The gold, after being cast into coin, requires to be annealed ; and in this process, when it has an alloy of copper, it acquires a brown or black colour, from the oxidizement of the copper at the surface. This is removed by washing with a solution of alum. The effect of this is to remove the oxide of copper ; and thus the surface of the coin is a film of pure gold. In the course of circulation, this is worn off, especially on the prominent parts : the colour of the alloy, which is deeper than that of pure gold, then appears ; and hence the unequal copper-like colour which coin that has been in circulation exhibits.

of this metal, which of course renders the addition less necessary. Mr Hatchet subjected the different alloys that have been used as coin to friction, as similar as possible to that to which they must be subjected in the course of circulation. The loss was by no means considerable; and it appeared as the general result, that the present standard gold, or alloy of one part of copper in 12, is, all things considered, the best, or at least as good as any that could be chosen. If the copper be in larger proportion, more loss is sustained from friction.

The same alloy is employed in the fabrication of plate, and of trinkets, and lace; and, by other additions, various shades of colour are obtained. Its alloy, with a fifth part of silver, forms the green gold of the jewellers; and the addition of iron gives a blue tint.

By gilding, other metals receive a coating of gold, more or less perfect, according to the method that is employed. The most substantial gilding is that effected by the medium of quicksilver on silver or copper. An amalgam is prepared of one part of gold, and eight of quicksilver: the surface of the metal to be gilt is cleaned by very dilute nitric acid, and is brushed over with a dilute solution of quicksilver in that acid, so that a thin film of this metal adheres to the surface: the amalgam is then applied, as equally as possible, by a wire brush. The metal is exposed to heat over a charcoal fire, or in a furnace of a particular construction: the quicksilver of the amalgam is volatilized, leaving a thin coating of gold. To render this sufficiently uniform, it is generally necessary that the amalgam should be applied more than once. The surface is lastly covered with a composition of wax, bole, alum,

acetate of copper, and sulphate of copper : it is exposed to a red heat to melt this off ; and by this its colour is heightened : it is then cleaned and burnished. Less substantial gilding is executed by merely dipping the metal in a mixed solution of muriate of gold, and corrosive muriate of mercury, and when dry exposing it to a red heat : or by macerating linen rags in a solution of muriate of gold ; burning them to tinder ; and rubbing this by a piece of cork, strongly on the surface of the polished metal, afterwards applying the burnisher. Iron or steel is gilt either by merely applying gold leaf to the metal, the surface of which has been well cleaned and heated, the surface being burnished, and this being repeated according as the gilding is required to be more or less durable : or by diluting the solution of gold in nitro-muriatic acid with alcohol, and applying it to the clean surface. This last process has been improved by Mr Stoddart. A saturated solution of gold in nitro-muriatic acid, being mixed with three times its weight of sulphuric ether, this dissolves the muriate of gold, and the solution is separated from the acid beneath. To gild the steel, it is merely requisite to dip it, the surface being previously well polished and cleaned, in the ethereal solution, for an instant ; and on withdrawing it, to wash it instantly by agitation in water*. By this method, steel instruments are now very commonly gilt.

Gold leaf affords another mode of applying this valuable metal. It has generally been supposed, that in making gold leaf the metal is employed pure : it would, however, be too soft and ductile to be uniformly extended. It is

* Nicholson's Journal, vol. xi. p. 215.

therefore hardened with from 3 to 12 grains of alloy in the ounce, silver or copper, or both, being used to form various shades of colour. The extension of it is performed by beating, after it has been brought to a certain degree of thinness, between pieces of animal membrane, on a polished anvil, with a polished hammer. The thickness of the leaf is about one two hundred and eighty-two thousandth part of an inch *. It is applied to wood by means of an adhesive size or glue, or sometimes by drying oil; to paper by the medium of a composition of the white of an egg, with sugar-candy, and a little bole. Glass is gilded by wetting the part with a solution of borax, applying gold leaf, and fixing it by burning: and porcelain is painted with gold, by mixing the powder obtained by evaporating the solution of muriate of gold to dryness with borax and a solution of gum, applying this by a pencil, and burning it in by the requisite heat.

Various tints of colour are given by the oxides of gold to glass and enamel. A rich red is communicated by the powder of Cassius; and even the fulminating gold has been applied to the same purpose.

* Nicholson's Journal, 4to, vol. i. p. 133.

CHAP. II.

SILVER.

SILVER is in some measure connected with gold, both by its physical and chemical qualities. It is possessed of great ductility and malleability, considerable lustre and specific gravity : it is with difficulty oxidized by the joint action of heat and air ; and its oxides, obtained by other processes, are like those of gold reduced by the action of heat alone. Not very abundant in nature, its comparative scarcity adds to the value it derives from these qualities, and has rendered it the medium of exchange next in estimation to gold.

Silver exists both native and mineralized, being combined with sulphur, oxygen, antimony, muriatic and sulphuric acids, forming a number of ores. Besides the proper ores of silver, there are also a number of metallic ores which contain this metal in small quantity, but often sufficiently great to render the extraction of it profitable : such are the grey copper ore, several varieties of sulphuretted lead, and zinc, and some cobalt and arsenical ores.

Silver is in general extracted without much difficulty. When native, it is separated from the earthy matter by washing, and amalgamation with mercury ; the latter being separated again by distillation. When alloyed with antimony, or arsenic, or when mineralized, the ore is roasted to expel these metals, the sulphur, or other volatile principles ; and the residual matter is fused with lead,

and refined by cupellation, in a manner similar to that which has been described under gold : the alloy of lead and silver being exposed to heat on the hearth of the refining furnace ; the lead being oxidized with the foreign metals, the oxidizement and vitrification of which it promotes ; and the vitrified oxide being in part absorbed, and in part driven off by the blast of the bellows. The appearance of a vivid incandescence, or brightening, denotes when the silver has become sufficiently pure. It retains a little gold in combination, but this does not alter its qualities, and the quantity is seldom such as to render its separation, by the operation of parting, an object of importance. Some improvements have been made by Duhamel in the process of refining silver, particularly in constructing the refining vessel of sand and clay, instead of bone or wood ashes, which are not procured but at a considerable expence, and in the mode of withdrawing the vitrified oxide as it is formed, from the surface of the melted metal *. If the ore which is wrought contain only a small portion of silver, the previous operation of eliquidation is performed on it. This consists in adding a certain portion of lead to the metallic matter which remains after roasting and fusing the ore. This alloy is exposed to a degree of heat just sufficient to melt the lead, which runs out, and, from its affinity to the silver, carries it with it, leaving the copper, or other metals with which the silver had been combined. The alloy of silver and lead is then subjected to the usual refining process.

Silver has a colour more approaching to pure white

* Nicholson's Journal, vol. xi. p. 206.

than that of any other metal ; in lustre it is superior even to gold ; but it tarnishes from long exposure to the air, not however from oxidizement, but from the action of minute quantities of sulphuretted hydrogen, which may be occasionally applied to its surface. Hence, it tarnishes more quickly in some situations than in others ; and when it has been exposed for a number of years, scales of sulphuret of silver form on its surface. In malleability it is inferior only to gold. The finest silver-leaf is about the hundred and sixty thousandth of an inch thick, which is one-third thicker than gold-leaf. In ductility it is inferior to gold, platina, and iron : still it possesses this property in an eminent degree ; it may be drawn into wire extremely fine, and a wire of it, 1-10th inch in diameter, supports, without breaking, a weight of 270, or, as has been stated, 370 lbs. It is harder than gold, is also more elastic, and is peculiarly sonorous. Its specific gravity is 10.47, and is increased by hammering, so as to be 10.51. It is tasteless and inodorous.

Silver requires a considerable heat to fuse it. Its melting point was stated by Mr Wedgwood to be at 28 of his scale. Sir James Hall has remarked, that it is not higher than 22° , measured by the pyrometer pieces that have been usually sold ; and Guyton has likewise stated it at 23° . When in fusion, its surface is extremely bright and luminous. By the usual method of allowing it to cool until it is congealed to some depth, and then piercing the solid crust, and withdrawing the liquid part, it is obtained crystallized in octaedrons. In congealing it expands ; hence the external crust, in the progress of the cooling, is burst by the expansion of the liquid within, and jets

of silver raised. By a stronger heat, as that of a powerful lens, it is volatilized, and it is even converted into vapour in the heat of a furnace.

Silver was believed to be equally difficult with gold of oxidizement by the action of heat and air. Macquer, by exposing it in a crucible twenty times successively to the intense heat of a procelain furnace, obtained, however, a small quantity of a vitrified oxide. The electric discharge, transmitted through silver-leaf between two plates of glass, oxidizes it, and vitrifies the oxide. Van Marum and Cuthbertson have found, that by passing the electric shock from a battery through a wire of silver, it is converted into an oxide of a blackish colour: a greenish flame appears at the moment of the discharge, and the oxygen of the air is consumed. By a powerful galvanic battery, silver-leaf is made to burn, emitting a beautiful green light. Lavoisier oxidized it by the heat excited by the flame of the blow-pipe, urged by a stream of oxygen gas; and a fine wire of it burns in the kindled united stream of oxygen and hydrogen gases. In the greenish yellow oxide that is precipitated from its solution in nitric acid, it has been supposed that about 10 parts of oxygen in 100 are contained. The darker coloured oxide obtained by its immediate combustion probably contains less. These oxides are decomposed by a high temperature, and the silver reduced to the metallic state.

Silver is oxidized by several of the acids, and combines with them. The sulphuric acid requires the assistance of a boiling heat; it is decomposed, sulphurous acid disengaged, and sulphate of silver formed with an excess of acid. The nitric acid acts upon it in the cold with great

rapidity; but in this, as in some other cases, it is indispensable to this action, that the acid should be diluted: if quite concentrated, the silver remains unaltered; but if a small quantity of water be added, the action commences, nitric oxide gas is discharged, and about half the weight of the acid of the metal is dissolved. Muriatic acid scarcely acts upon it, but it is oxidized by the oxy-muriatic and nitro-muriatic acid.

Of these salts the sulphate of silver is nearly insoluble in water. It is most readily formed by adding sulphuric acid to the solution of silver in nitric acid: the sulphate of silver is precipitated. By boiling water upon it, a small quantity of it is dissolved; and on cooling, small needle-like crystals are deposited. It is blackened by exposure to light; and by a red heat is decomposed, its acid being expelled, and the metal reduced. Sulphurous acid may likewise be combined with oxide of silver. By adding it to the solution of nitrate of silver, a precipitate is formed of a white powder, which is very sparingly soluble in water. According to Fourcroy, sulphate of silver is not blackened by light; it is decomposed by heat.

The nitrate of silver is readily formed by pouring diluted nitric acid upon silver, the metal being rapidly oxidized and dissolved. The solution has at first a blue or green colour, but when the silver is pure, this is owing only to part of the nitric oxide arising from the decomposition of the acid being retained by the liquid. It soon disappears, and the solution remains colourless. It remains permanently green, however, if the silver has contained even a minute portion of copper. If any gold has been present, it falls down in a black powder. The

solution, if the acid has been pure, is limpid : but if the smallest portion of muriatic or sulphuric acid has been present, it remains turbid, until the muriate or sulphate of silver subsides. It is extremely caustic, first tinging any animal substance of a black colour, and consuming it if longer applied. When saturated, it shoots into brilliant white crystals in plates : easily soluble in water, and permanent in the air. They consist of 64 parts of oxide of silver, 22 of acid, and 14 of water. This salt is speedily blackened by exposure to light from a reduction of part of the metal : it is fused by a very moderate heat, its water of crystallization being expelled. This, run into moulds so as to form small cylinders, is the pharmaceutic preparation, known by the name of Lunar Caustic, what ought to receive the name of Sub-nitrate of Silver, as it always is deprived of part of its acid in its fusion. It is the most powerful, and at the same time the most convenient in its use of all the escharotics, giving less pain, and being more easily confined to the part to which it is applied. By continuing the application of heat to the nitrate of silver after it is fused, it is decomposed, the nitric acid being expelled, and the silver partially reduced. It detonates with ignited charcoal, and is reduced. It detonates violently too, as Brugnatelli has shewn, when struck on an anvil smartly with phosphorus ; and if the hammer has been heated, it detonates even with sulphur. A nitrate of silver at the *minimum* of oxidation, much more soluble than the other, and less disposed to crystallize, may be obtained, according to Proust, by boiling a solution of the common nitrate with metallic silver *.

* Nicholson's Journal, vol. xv. p. 376.

Muriatic acid scarcely acts on silver. According to Proust, however, it converts it slowly into muriate hydrogen gas, being evolved. It has a strong attraction, likewise, to its oxide, and added to a solution of silver in nitric acid, it attracts the oxide, and the muriate of silver which is formed, being insoluble, is precipitated. By this agency it is the most delicate test of the presence of silver; and, on the other hand, nitrate of silver is the most delicate re-agent to discover muriatic acid. The muriate of silver is also formed by the action of nitro-muriatic acid; the nitric acid affording oxygen to the metal. It is likewise formed by the action of oxy-muriatic acid; or by adding to muriatic acid an oxide of silver. The muriate of silver contains 75 parts of oxide of silver, 18 of acid, and 7 of water: it is scarcely soluble in water: it is very sensible to the presence of light, being blackened in the course of one or two minutes exposure to the solar rays; and from this property is the most sensible test of the intensity of the chemical agency of light. This blackening has been supposed to be owing to the partial reduction of the oxide, from the light expelling a portion of its oxygen, in conformity to the usual chemical agency it exerts. Scheele observed, that when the salt was placed under water, and exposed to the light, the water acquires a little acid. This has been since examined by Berthollet, who has found, that the water acquires so much acid, as to redden litmus paper; a proof that it is not the oxy-muriatic, but muriatic acid that is disengaged; nor has he found any traces of the disengagement of oxygen. The blackening appears to be owing solely to the partial disengagement of acid; it is

produced likewise, as he has observed, by heat, muriate of silver becoming black before it enters into fusion, and a little muriatic acid without any oxygen being disengaged. And it appears to be effected even by the action of the air; as muriate of silver, exposed in a dark place to a current of air, became black*.

Muriate of silver is extremely fusible: by a gentle heat it may be fused in a matrass into a dense liquid: on cooling, it concretes into a substance, of a pearl grey colour, semi-transparent, soft, and possessing some degree of flexibility and malleability, which, from these properties, acquired from the older chemists the name of *Luna Cornea*, or *Horn Silver*. Sometimes octaedral crystals are obtained from it by fusion. By a higher temperature it is decomposed: both its acid and the oxygen of its oxide are expelled, and the metal is reduced and fused. This has even been employed in practical chemistry, as the best method of obtaining pure silver; as when the silver is precipitated from its solution in nitric acid by muriatic acid, it is pure; copper, or various other metals which may have been alloyed, and of course dissolved along with it, still remaining in solution. The decomposition of the muriate by heat, is facilitated by the action of an alkali. Hence, in the process generally followed to obtain pure silver, one part of the muriate is mixed with four parts of sub-carbonate of potassa, and the mixture is exposed to a full red heat in a large crucible, or, what is more secure, in a phial placed in sand in a crucible. When it has been brought fully into fusion, the crucible is re-

* *Chemical Statics*, vol. i. p. 147.

moved, and allowed to cool slowly : a mass of pure silver is found at the bottom.

From the action of oxy-muriatic acid on silver, we obtain only a muriate, the oxygen serving to oxidize the metal. But Mr Chenevix has found, that if a current of oxy-muriatic acid gas be passed through oxide of silver suspended in water, a hyper-oxymuriate is formed. The same salt is produced by another process which he gives,—that of forming hyper-oxymuriate of argil, by passing a current of oxymuriatic acid gas through water in which argil is diffused : then digesting phosphate of silver with the hyper-oxymuriate of argil, when hyper-oxymuriate of silver is formed. It is abundantly soluble in water, requiring only two parts of hot water for its solution : this solution affords rhomboidal crystals of a small size on cooling, which are white and opaque. It is also soluble in alcohol. Exposed to heat, it is fused and decomposed, the excess of oxygen being given out. A grain or two of it, mixed with half its weight of sulphur, and struck, or rubbed, detonates with a loud report and a vivid flash*.

The combinations of silver with the other acids have been little examined. In general, they are sparingly soluble in water. They may be formed most easily, by adding to the solution of silver in nitric acid, either the pure acid with which it is designed to combine the oxide of silver, or a neutral salt, into the composition of which that acid enters. The phosphate of silver prepared in this way, forms a dense white precipitate, which is not soluble in water, but may be dissolved in an excess of

* Philosophical Transactions, 1802, p. 162.

phosphoric acid. It is fused by heat into a greenish opaque glass; when heated with charcoal, phosphuret of silver is formed. Carbonate of silver may be obtained by a similar process, in the form of a white powder, insoluble, which is blackened by light, and decomposed by heat, so as to afford pure silver. The fluuate and the borate of silver are equally insoluble.

The saline compounds of silver are decomposed by the alkalis and earths. As the nitrate of silver, from its solubility, is best adapted to display the phenomena of these decompositions, it is principally with regard to it that they have been examined.

Potassa added to its solution, throws down a precipitate which varies in its colour, probably according to the state of the solution, from a yellowish white to a brown or green, and which, though supposed to be an oxide, is probably a sub-nitrate. It is decomposed by heat, being reduced to the state of metallic silver. Soda and lime exert a similar action. Ammonia occasions a precipitate of a grey colour, sometimes approaching to black, owing probably to the partial abstraction of oxygen from the oxide by the hydrogen of the ammonia. It possesses no fulminating property. Ammonia, however, has a strong tendency to re-act on oxide of silver, and combine with it, but it forms a soluble compound: hence, a slight excess of ammonia added to the solution of silver, redissolves the precipitate, forming a purple salt, and the liquor acquiring a brown colour.

A fulminating silver, however, can be formed, composed of ammonia and oxide of silver, which is incomparably more powerful than the fulminating gold. The pro-

cess was discovered and described by Berthollet *. It consists, in adding to a solution of nitrate of silver, lime-water : the precipitate which is formed, is dried by exposure to the air for two or three days : it is then stirred in liquid ammonia : it thus assumes the form of a black powder, from which the liquor is to be poured off, and which is to be left to dry. This, according to Berthollet, is the fulminating silver. When the liquid, which has been decanted, is evaporated in a glass-vessel, it deposits, after it is cold, minute crystals : these detonate with the utmost violence : one of them being touched, is sufficient to burst the vessel with an explosion, and disperse the liquor. According to Dr Higgins, it is this crystallized matter which is the proper fulminating silver ; and the black powder that is first deposited when the oxide of silver is stirred in the ammonia, owes its detonating quality to the intermixture of a portion of it.

This latter chemist has given more precise directions for preparing fulminating silver ; the process, as concisely described by Berthollet, having frequently not succeeded with chemists. One part of silver is to be dissolved in one part of pure nitrous acid, diluted with three parts of distilled water : the solution, when completed, is to be poured off from a small quantity of black powder, which remains undissolved : this residual matter is to be washed with seven or eight parts more of distilled water warm, and this is to be added to the solution. To this is to be added lime-water, in successive portions, as long as any considerable precipitation is occasioned, taking care not

* Journal de Physique, tom. xxxii. p. 475.

to add an excess ; and the precipitate is to be put on a filtre, and washed with successive portions of distilled water : the filtre is then unfolded with the precipitate upon it, and placed on a chalk-stone to accelerate the exsiccation, in the open air ; a piece of paper being placed over it to exclude dust. When dried, this matter is to be stirred in pure liquid ammonia ; the liquor is to be poured off from the insoluble powder, and exposed in a shallow vessel to the air. Black shining crystals form on the surface, and unite so as to form a pellicle, and the liquid may be withdrawn by a gentle inclination of the vessel. It will yield by a new exhalation another pellicle, and this even for a third or fourth time ; but these are paler than the first, and weaker in the explosion. This matter is the proper fulminating silver*.

Such is the tendency of this preparation to detonation, that the slightest friction or percussion is sufficient to occasion it : it cannot be removed from the vessel in which it is prepared, nor even touched ; the falling of a drop of water on it, or the accidental concussion of the vessel containing it, is sufficient to cause its explosion ; and so violent is the explosion, that the experiment cannot be made with safety on a larger quantity than about a grain. Accidents have repeatedly happened from the utmost caution not having been observed with regard to it. One is related by Dr Higgins, in which a quantity of a strong solution of ammonia had been poured on the precipitated oxide of silver, and the vial corked. It had been agitated two or three times in the course of as many hours ; after

* Minutes of a Society for Philosophical Experiments, p. 344.

that, again agitating it, although no film had appeared on the surface, it exploded with the utmost violence, and the hand was impressed as by the blow of a large hammer. In making experiments with it, a mask, as Berthollet recommended, ought always to be put on.

The theory given by Berthollet of the detonation of this preparation, is the same as that of fulminating gold. He regards it as a compound of ammonia and oxide of silver: the friction or percussion causes an approximation of the elastic principles; the oxygen of the oxide, and the hydrogen of the ammonia, instantly combine, forming watery vapour: the nitrogen, at the same time, assumes the elastic form; and the elasticity of both is augmented by the caloric set free. It has not been attempted to account for the much greater detonating power of this preparation, compared with that of fulminating gold. Perhaps it may be owing to the oxide of silver containing a larger quantity of oxygen than oxide of gold does, and to this oxide attracting also a larger portion of ammonia; so that a larger quantity of principles, disposed to enter into new combinations, and form elastic products, is contained in a given quantity: and hence, both the greater susceptibility of detonation and its greater violence. In all these preparations, it must be supposed, that a large quantity of caloric remains with the oxygen in the combination which forms their base.

Another fulminating silver has been described by Brugnatelli. In the process which he gives for preparing it, 100 grains of the fused sub-nitrate of silver, or lunar caustic, in powder, are put into a glass, one ounce of alkohol is poured on it, and then as much concentrated

nitrous acid. The mixture becomes hot with effervescence; it also becomes milky and opaque. When the grey powder of the sub-nitrate has become white, and the mixture acquired a consistency, distilled water must be added to suspend the action: the white precipitate is collected on a filtre, and dried: it is the fulminating preparation. It resembles in its operation a fulminating quicksilver prepared by a similar process, discovered by Mr Howard, being only more powerful. A grain of it thrown on burning fuel gives a loud report; and it detonates with extreme violence when touched with a glass-rod that has been dipt in sulphuric acid*. A similar composition has been described by Descostil. It is prepared by dissolving silver in nitric acid, and pouring into the solution while it is going on a sufficient quantity of alcohol. An effervescence takes place, the liquor becomes turbid, a white crystalline powder falls down, which is removed when it ceases to increase, and is washed. Heat or percussion causes it to explode with violence, and sulphuric acid inflames it. Muriatic and nitric acid decompose it. Ammonia dissolves it without changing its properties†.

The action of the alkalis on the other salts of silver is similar to that which has been described with regard to the nitrate. They attract the greater part of the acid, and form precipitates of the oxide, probably with a portion of the acid combined with it. According to the observations of Vauquelin, however, they do not decompose the muriate. On boiling a solution of soda on muriate of

* Nicholson's Journal, vol. vii. p. 285.

† Nicholson's Journal, vol. xviii. p. 140.

silver, he did not find that any of the muriatic acid was attracted by the soda; and, on the contrary, oxide of silver newly precipitated from the solution in nitric acid, when thrown into a solution of muriate of soda, was converted into a soft curdled mass, exactly resembling muriate of silver formed in the common way; and the liquor above became alkaline. These effects are in some measure to be ascribed to the influence of quantity on affinity; as a large proportion of oxide of silver was found necessary to decompose the muriate of soda. The relation of muriate of silver to ammonia is also peculiar. Instead of being decomposed, a ternary combination is established, the product of which is abundantly soluble: hence, liquid ammonia dissolves muriate of silver: the solution is at first colourless, but, when left exposed to the air, a pellicle of a grey or blue colour forms on its surface, which increases slowly and precipitates,—a change arising partly from the exhalation of the ammonia, and partly from its re-action on the oxide, which it partially reduces.

The salts of silver are decomposed by the inflammables, and the greater number of the other metals. These experiments have been made principally on the nitrate, as its solubility allows the affinities from which the decompositions arise to operate. Its watery solution is reduced by hydrogen gas, phosphorus, and other inflammables, when they are applied in the manner already described under the history of gold. Charcoal immersed in the dilute solution, and exposed to the sun-beams, is coated with reduced silver. The decompositions by the metals are some of them partial, others complete;—differences arising not only from the different affinities of metals to

oxygen, but from the affinity also exerted towards the silver. Iron, copper, and quicksilver, throw it down in the metallic state. The precipitation by iron appears, from the researches of Mr Keir *, to require that the silver in the solution should not be in a high state of oxidizement, and there should be some excess of acid: under these circumstances it is metallic silver. The precipitation by copper is easily effected; a plate of copper immersed in the nitrous solution, being instantly covered with a pellicle of reduced silver, which accumulates, and is easily detached from the copper. This process is followed, in the art of assaying, to recover the silver which has been alloyed with gold, and which, in the operation of parting, has been dissolved by nitric acid; plates of copper being put into the solution, so as to precipitate the silver: it is also frequently employed to obtain silver free from other metals with which it has been alloyed. The silver thus precipitated, has a small quantity of copper combined with it; but from this it may be freed by cupellation, and it is then extremely pure. The precipitation of silver from its solution by quicksilver, when effected slowly, gives rise to a crystallized arrangement, similar in appearance to arborescence, and hence forming what the chemists named *Arbor Dianæ*. It may be effected by putting a little quicksilver into a dilute solution of nitrate of silver, but it is sooner obtained by the process given by Homberg; in which four parts of silver, with two of quicksilver, are dissolved in a sufficient quantity of diluted nitric acid, and diluted with forty-eight

* Philosophical Transactions, 1790.

parts of distilled water. When a small piece of soft amalgam of silver is dropt into a little of this solution, in a short time filaments of reduced silver shoot from this, and extend upwards, giving the appearance of a shrub. This precipitation of the silver, is occasioned by the quicksilver of the amalgam attracting its oxygen, favoured by the affinity of the silver to the quicksilver, and probably also by the cohesive attraction of the silver of the amalgam.

Silver combines easily with sulphur by fusion, or rather by exposing thin plates of silver, imbedded in sulphur, to such a heat as melts the sulphur. The sulphuret is of a deep violet colour, approaching to black; with a degree of metallic lustre; opaque, brittle, and soft. It is more fusible than the metal, and this in proportion to the quantity of sulphur combined in it. Heat, raised sufficiently high, decomposes it, and expels part of the sulphur. Sulphur appears also to be capable of combining with oxide of silver, at least such combinations exist in nature. Sulphuretted hydrogen soon gives to the surface of polished silver a violet tinge; and by continued exposure, a thin layer of sulphuret of silver is formed. The precipitate thrown down by the solution of sulphuretted hydrogen, or of a hydro-sulphuret, from a solution of silver, which is of a black colour, is probably of a similar nature. The alkaline sulphurets, exposed to heat with silver, combine with it, and form a compound which is soluble in water, and from the solution of which the acids throw down sulphuret of silver.

Silver and phosphorus are capable of combining by the process of Pelletier, already described. The compound exceeds in weight the silver employed about one-fourth,

which shews the quantity of phosphorus combined. It is white ; of a granular texture ; soft and brittle. It is decomposed, at least partially, by heat.

Silver is capable of entering into combination with the greater number of the metals : in these alloys, except that with gold, its ductility is generally impaired. The alloy with gold can be formed in various proportions, and according to these its properties vary. These proportions seem to be in some measure regulated by the difference in their specific gravity ; for, according to an experiment long ago related by Homberg, when the two metals in equal proportions are melted together, on allowing the alloy to cool and congeal, that part of it at the bottom of the mass is almost pure gold, or at least contains not more than about a seventh part of silver, while that at the top is nearly pure silver. When fused in other proportions, however, and when not kept long in fusion or allowed to cool slowly, various alloys can be formed. The density is little increased by the combination, so that the specific gravities of the alloys differ little from those which, according to the calculation, would result from the relative proportions of the metals. The silver communicates hardness and elasticity to the gold, without very much diminishing its ductility. It impairs its colour, however, greatly. From different proportions are obtained the pale yellow and the green gold of the goldsmiths. The alloy being more fusible than pure gold, is used in soldering this metal.

Silver is used as a medium of exchange, and to fabricate a variety of ornamental vessels. The applying it to the surface of copper or other metals, or plating, as it is named, is performed in different modes. The most sub-

stantial is that of applying a thin plate of silver to a bar of copper perfectly clean, putting a little borax between them. The two, well bound together, are exposed to a red heat, the borax melts, and the silver adheres to the copper. The bar is then passed through the rolling-press, and is thus extended. French plating is performed by applying leaves of silver successively to heated copper, and fixing them by burnishing. Another mode is to make silver into an amalgam with quicksilver, and the copper having been cleaned, and dipt in a dilute solution of quicksilver in nitric acid, the amalgam is applied to it; the plate is then heated, so as to volatilize the quicksilver, and favour the combination of the silver at the surface of the copper: it is afterwards burnished. Less durable silvering is effected by various methods, as by rubbing on the surface of the metal to be silvered, a mixture either of silver precipitated from its nitrous solution by copper, or of muriate of silver, with muriate of soda, and super-tartrate of potassa, or a mixture of silver, precipitated by copper, with muriate of soda, muriate of ammonia, and a little corrosive muriate of mercury. The silver adheres to the surface of the copper, and the adhesion is rendered more permanent by the application of heat. By this last method, the scales of thermometers and barometers, and the dial-plates of clocks, are silvered.

It is an object of some importance, to recover the silver from plated goods which have been injured by wear. The process by eliquidation and cupellation is too expensive. A method formerly in use, though lately proposed by Göetling as new *, was to boil the plated metal in sulphuric

* Nicholson's Journal, vol. xi. p. 142.

acid, which oxidized and combined with the two metals. The sulphate of copper was separated by washing, and the sulphate of silver reduced. Some years ago Mr Keir discovered a method which is now practised in this country. He observed that a compound acid, formed of sulphuric and nitric acids, has the property of dissolving silver with facility, while it does not dissolve copper; and it occurred to him, that it might be employed to separate these metals. The process which he recommended *, is to dissolve one pound of nitre in eight or ten pounds of concentrated sulphuric acid, with a moderate heat, in an earthen-glazed pan, adding to this liquor the plated copper in small pieces or shreds, stirring them frequently, so as to renew the surface, and assisting the mutual action by a heat of from 100° to 200° of Fahrenheit's scale. When the silver appears to be entirely dissolved from the copper, the liquor is to be poured off, and the oxide of silver may be precipitated in the state of muriate of silver by the addition of muriate of soda, this muriate of silver being reduced by the usual method: or, instead of these latter steps of the process, the solution of silver may be diluted with water; the diluted compound acid is capable of dissolving copper, though the concentrated is not: in the dilute solution, therefore, copper plates may be immersed, and the silver will be precipitated in its metallic form. Mr Thomson has also lately pointed out an easy process for separating silver from copper, where the silver is in large proportion: it consists in exposing the silver in thin pieces, imbedded in powder of black oxide of man-

* Philosophical Transactions, 1799.

ganese in a crucible, to a heat sufficient to melt silver : it is thus converted into an uniform black powder. This is mixed with three times its bulk of pounded green glass, and again exposed to a heat sufficient to melt the glass. On cooling, the silver is found at the bottom of the crucible perfectly pure, as the oxidized copper cannot be reduced from no inflammable matter being present, while the high temperature is sufficient to reduce the silver alone. Gold may be purified by the same process *.

The solution of nitrate of silver is used in analytic chemistry to discover the presence of muriatic acid in any state of combination. It is also employed, when much diluted, for marking linen which is to be bleached, forming what is named Indelible Ink, and for darkening the hair, and, as has been already stated under the chemical history of light, for taking copies of paintings on glass.

CHAP. III.

PLATINA.

THIS metal, found principally in Peru, was unknown in Europe, until mention was made of it by Ulloa, in his relation of the voyage undertaken by the French Academicians to that country in 1735, to measure a degree of the meridian, with the view of determining the figure of the earth. Wood, an English metallurgist, brought a quantity of it from Jamaica in 1741, and gave

* Nicholson's Journal, vol. xi. p. 125.

an account of some of its properties. A more complete investigation of these was undertaken by Scheffer, and published in the Acts of the Academy of Sciences at Stockholm in 1753, and also by Lewis, published in the Philosophical Transactions for 1754. Since that period, it has engaged the attention of a number of eminent chemists, and the details of its history were supposed to be nearly complete. Within these three or four years, however, some interesting discoveries have been made with regard to it; not less than four distinct metals having been found to exist associated with the metal to which the name of Platina properly belongs.

Native Platina is in the form of grains, and it had always been observed, that in dissolving these in nitro-muriatic acid, a quantity of a black powder, amounting to about three parts in 100, remained undissolved. With regard to the nature of this, different conjectures had been made; latterly, it was generally supposed to be a carburet of iron: Descostils, however, undertook more particularly the examination of it: he observed, that if this black matter, which is precipitated as the solution proceeds, be not removed, part of it is again dissolved, and gives to the solution a darker colour than it would otherwise have; and when this solution is decomposed by adding a solution of muriate of ammonia, the precipitate thrown down is darker than when the powder had been removed. This black matter by itself is capable of being dissolved, though with difficulty, in nitro-muriatic acid which contains much nitric acid; and on adding to the solution muriate of ammonia, a dark red precipitate is thrown down. This precipitate was examined by Descostils, and there-

sult was, that the substance which gives to it the red colour, which gives a similar colour to the solution of crude platina, and which forms a principal part of the black powder deposited during the solution, is a metal before unknown. He found, too, that it can at once be sublimed in the form of a blue oxide from native platina, by a strong heat applied in close vessels *. Nearly about the same time, the discovery of this metal was made by Vauquelin †; and in this country by Mr Tennant ‡. The latter chemist observed its properties more fully; and from the property which it has of exhibiting a striking variety of colours, while dissolving in muriatic acid, he gave it the name of *Iridium*.

But Mr Tennant found, that another metal exists in the black powder, which is precipitated while crude platina is dissolving in nitro-muriatic acid. It is obtained by exposing this powder with a large proportion of soda, in a silver bason, to a red heat. On adding water to the mass when cold, a solution of a deep orange colour is obtained, a considerable portion remaining undissolved, which is chiefly iridium. The alkaline solution contains the other new metal in the state of an oxide in combination with the soda. It had been noticed by Vauquelin, who regarded it as the combination of another metal, chrome, with the alkali. But of this Mr Tennant could discover no trace; and finding, by further investigation,

* Journal de Physique, tom. lvii. p. 384. Nicholson's Journal, vol. viii. p. 118.

† Annales de Chimie, tom. xlix. p. 188. 219. tom. l. p. 1.

‡ Philosophical Transactions, 1804, p. 411.

that the metallic substance thus obtained has properties sufficient to discriminate it from every other, he regarded it as a peculiar metal. From the pungent smell of its oxide, which is one of its most distinguishing characters, he gave it the name of *Osmium* *.

Dr Wollaston, prosecuting these investigations, has discovered other two metals in Crude Platina. His attention was more particularly directed to the solutions obtained by the action of nitro-muriatic acid on it, and the decompositions these suffer; as in these, appearances are presented, which he could not ascribe to either of the other metals, or to any known substance †.

A property belonging to platina, and which had often engaged the attention of chemists, is that of affording a copious precipitate when muriate of ammonia is added to its solution in nitro-muriatic acid. Dr Wollaston found, that after this precipitation was complete, or when no further change was produced in the solution by muriate of ammonia, there still remained in the liquid a metallic substance in solution, which might be in a great measure precipitated by immersing a plate of iron or zinc. On dissolving this precipitate in pure nitro-muriatic acid, precipitating any platina from the solution by muriate of ammonia, and allowing the remaining liquid to evaporate spontaneously, among crystals which are deposited, are some of a deep red colour; which, when picked out, and exposed to heat, yield a portion of muriate of ammonia, and a black substance remains, which, by a more intense

* Philosophical Transactions, 1804, p. 416.

† Ibid. 1804, p. 419.

heat, acquires metallic brilliancy. The properties of this metal were examined by Dr Wollaston. From the examination, he found reason to conclude, that it is essentially different from every other, and from a peculiar distinctive character of it,—that of the dilute solutions of the salts containing it having a rose colour, he gave it the name of *Rhodium**.

Lastly, Dr Wollaston found, in the solution of crude platina in nitro-muriatic acid, still another metal, of very valuable properties, which he named *Palladium*. When the solution of crude platina in nitro-muriatic acid is decomposed by muriate of ammonia, and the precipitate has subsided, the remaining liquid contains iron in solution with rhodium and with this other metal palladium. By immersing a plate of zinc in it, a precipitate is thrown down nearly free from iron, and consisting of these two metals with a little platina. It is dissolved in diluted nitro-muriatic acid, and a small quantity of muriate of soda is added to the solution, which is then evaporated to dryness: the saline matter obtained consists of triple salts of platina, palladium, and rhodium, with soda, and muriatic acid. The muriate of soda and palladium is separated from the other by washing with alcohol, which dissolves it, while the muriate of soda and rhodium remains undissolved: any small portion of muriate of platina which may be dissolved, is precipitated by muriate of ammonia: on now adding to the solution prussiate of potassa, a precipitate of a deep orange colour, which changes to a green, is thrown down: this precipitate is reduced by heat to the

* Philosophical Transactions, 1804, p. 419.

metallic state, and this is the palladium *. Other processes have since been given by Dr Wollaston, by which it may likewise be obtained †. Palladium was offered for sale before any thing was made public with regard to its origin. Mr Chenevix supposed that he had discovered it to be an alloy of platina and mercury; but his experiments in proof of this have not succeeded with other chemists; and there is reason to believe, that the properties he observed in some of the compounds he formed had arisen from the palladium which platina contains.

Should the discovery of these four metals be confirmed, it will place in a striking point of view the delicacy and accuracy of the methods of modern chemical analysis, as, taking them together, they do not amount to above a twelfth part of the crude platina. Yet it must be acknowledged, that some doubt may be entertained with regard to their existence as distinct metals; since it is not impossible that they may be alloys of others; or that the peculiar properties which they appear to exhibit, may arise from combinations which analysis has not detected. The peculiarity of their association in one natural production, while there are no traces of them in any other, perhaps lends force to this supposition.

It is likewise to be admitted, however, that the same suspicion may be entertained with regard to several others of the newly discovered metals; and that the properties of those above described, are as distinctive as those belonging to these others. The safest mode may be to re-

* Philosophical Transactions, 1804, p. 426.

† Ibid. 1805, p. 316.

ceive them as distinct substances until the reverse is established. This will, of course, lead me to give their chemical history apart, and the remaining part of this chapter will be devoted to the history of the metal, to which the name of Platina still properly belongs.

Native Platina is brought from Peru, and has more lately been discovered by Vauquelin, in the ores of the mines of Guadalcanal in Spain. It is generally as imported from America in small flattened grains, though pieces of a larger size have sometimes been found. It is not pure, but is mixed with the different substances already mentioned; and, according to Dr Wollaston, in the grains which are considered as platina, there are two substances different from each other. Some of these grains are much harder than the others; are not malleable; have a laminated structure; and are heavier, having a specific gravity equal to 19.5; while that of the softer grains, which consist of the platina, is only 17.7: the former did not appear, on analysis, to contain any platina, but to be an alloy of iridium and osmium *. Besides these intermixtures, the platina itself is an alloy; it is after fusion sensibly magnetic from the presence of iron: and from the researches hitherto made, it is not very easy to discover, whether the four metals found to be associated with it are all in a state of combination, or whether any or all of them are merely interspersed among its grains. If the existence of these metals be fully established, it must be admitted that we know little of even the physical qualities of platina in a pure state; for although in the processes by

* Philosophical Transactions, 1805, p. 317.

which it is purified, they are in part abstracted, it is certain from what we know of the habitudes of these metals, that by these processes they will not be entirely removed. In dissolving it, it may be obtained more pure, yet we are not certain that in any combination it is obtained perfectly free of alloy; the properties of pure platina must be regarded at present, therefore, as not ascertained with perfect accuracy. This observation will require to be kept in view in its remaining chemical history.

From the extreme infusibility of platina, its grains cannot be united by fusion, so as to obtain it in a solid or dense mass: various indirect processes have, therefore, been adopted for this purpose.

De l'Isle appears first to have succeeded in obtaining malleable platina. This he did by dissolving crude platina in nitro-muriatic acid, throwing down a precipitate by muriate of ammonia, and exposing this precipitate, which is a muriate of ammonia and oxide of platina, to a very violent heat. The muriatic acid and ammonia were dissipated; the oxide of platina reduced, and the metal agglutinated; and by pressing it while red hot, this agglutination was rendered more perfect.

Margraaf observed, that by alloying platina with arsenic, it was rendered more fusible; and Guyton proposed, and even carried into execution, this method of obtaining platina in a state fit to be wrought. It was adopted with various modifications by several chemists; and Jeannety of Paris succeeded by it in working platina into wire, plates, and vessels of different kinds, adapted chiefly to chemical purposes. The following account of his process was given in a report by Pelletier*.

* *Mémoires de Chimie*, tom. ii. p. 128.

The crude platina is trituated with water, to remove any particles of iron, or other impurities mixed with it. One pound and a half of it are mixed with three pounds of white arsenic, and one pound of purified potash, (sub-carbonate of potassa); a crucible capable of containing 20 pounds is placed in a furnace, so as to be well heated; and a third part of the above mixture is thrown into it: after applying to this a strong heat, a second portion is thrown in, and afterwards the remaining part, care being taken to mix the whole by stirring with a rod of platina. The heat is raised, and when the whole is thoroughly melted, the crucible is withdrawn, and allowed to cool. The metallic mass thus obtained is magnetic: it is broken and melted a second time in the same manner: and if this second fusion does not free it sufficiently from iron, it is fused a third time, though in general two fusions are sufficient. This first stage of the operation being finished, crucibles are taken, the bottom of which is flat, and the circumference such as to give a mass of metal three inches and a quarter in diameter: they are raised to a red heat, and into each is thrown a pound and a half of the metallic substance obtained in the former part of the process, with an equal weight of arsenic, and half a pound of potash: the heat is raised so as to melt this completely: the crucible is then withdrawn, and allowed to cool, placing it horizontally, so that the bar of metal shall be of equal thickness. The bars thus obtained are placed in a furnace under a muffle, which ought not to be higher than the circumference of the bars placed on edge, and inclined a little towards the sides of the muffle; three bars are placed on each side of it; the fire is raised

until the muffle be equally heated through its circumference ; and whenever the metallic bars begin to exhale vapour, the doors of the furnace are closed to preserve the heat at the same degree, it being necessary that it should be kept so to the end, as, if suddenly raised high, the whole operation would be defeated. The bars are exposed to this heat for six hours, their places being changed occasionally, that they may be heated as equally as possible. They are then put into common oil, and are exposed for the same length of time to a heat sufficient to dissipate the oil in vapour. This operation is continued as long as any vapour arises from the bar ; and when this has ceased, the heat is pushed as far as it can be by the medium of the oil, a step of the process without which the platina is not obtained perfectly malleable. When these operations have been finished, which, when they have been properly executed, require about eight days, the bars are cleansed with nitrous acid, and are boiled in distilled water, to remove any adhering acid : they are then placed one above another, and exposed to the strongest possible heat, and beat ; the heat being at first applied to them in a crucible, that no foreign matter may be introduced into the spongy substance of the bars. They are lastly heated in the naked fire, and formed into a square bar, which is hammered for a longer or shorter time according to its size. This is on the whole the cheapest method of rendering platina malleable : but the metal is probably far from being pure.

Pelletier proposed to render platina fusible by phosphorus, the platina being exposed to heat with phosphoric acid and charcoal, and a phosphuret being formed ;

this is very fusible, and by exposure to a low heat, the phosphorus is burnt out. He acknowledges, however, that it is difficult to separate the last portions of phosphorus; and the process has not been adopted by any artist *.

The following process was given by Moussin Poushkin. The precipitate of platina from nitro-muriatic acid is to be washed with cold water, and reduced, by exposure to heat in a crucible, to the spongy metallic substance, which is usually obtained by this operation. This is to be washed two or three times with boiling water, to carry off any adhering saline matter. It is then to be boiled for half an hour in so much water mixed with one-tenth of muriatic acid, as will cover the mass to the depth of about half an inch in a glass-vessel; this removing any quantity of iron that might exist in the metal. This liquid is to be poured off, and the platina is to beedulcorated and ignited. To one part of this metal, two parts of quicksilver are to be added, and they are to be amalgamated in a glass or porphyry mortar; mixing them in small quantities at a time, as two drachms of mercury to three of platina, and adding to this amalgam alternately small quantities of platina and mercury, until the whole quantities are combined. In this way, and with platina in this state, the amalgamation is easily effected. When the amalgam has been completed, it must be quickly moulded in bars or plates, of at least half an inch in thickness, and of such a length as to allow of their being easily managed in the fire. Half an hour after these have been formed, they begin to harden by the oxidizement of the quicksilver.

* *Mémoires de Chimie*, tom. ii. p. 132.

As soon as they have acquired the proper degree of hardness to be handled without breaking, which commonly takes place in a little more than an hour, they are to be placed in a furnace, and kept ignited under a muffle. The quicksilver is thus expelled, and the platina remains perfectly solid, so that after being strongly ignited two or three times before the bellows, it may be forged or laminated in the same manner as gold or silver *. Still some of the metals naturally associated with it, must remain combined with it.

A very simple process has been given by Mr Tilloch. It consists in exposing the precipitate from the solution of platina in nitro-muriatic acid, by muriate of ammonia, to a heat sufficient to volatilize the saline matter, and inclosing it after this in a piece of platina already malleable, and which has been spread out by the flatting-mill. The envelope is exposed to a sufficient temperature, and, while hot, is cautiously hammered. This is repeated until it is obtained in a compact state †.

Any of the preceding operations designed to obtain pure platina, ought to be performed on the grains of crude platina, which have been separated from the foreign substances usually mixed with them. The easiest way of doing this, is spreading the grains on a sheet of paper, and blowing obliquely a current of air on them slowly by a bellows; the lighter substances are separated, while the platina grains, from their greater weight, remain. The ore of iridium, which is mixed with the platina, in grains

* Nicholson's Journal, vol. ix. p. 65.

† Philosophical Magazine, vol. xxi. p. 175.

very similar, ought also, as Dr Wollaston has remarked, to be picked out. The separation, however, must in this way be always imperfect; and as iridium is dissolved by nitro-muriatic acid, and also precipitated by muriate of ammonia, platina obtained from this precipitate must always have an alloy of this metal. To avoid this, another process has been given by Descostils. It is very complicated, but the principal steps are to melt crude platina with zinc; to dissolve the alloy in sulphuric acid diluted with thrice its weight of water, promoting the solution when it begins to cease, by the addition of a little nitric acid; to dissolve the metal remaining after this operation in nitro-muriatic acid, then to pour off this solution clear, and evaporate it to dryness: The dry matter is dissolved again in water, and carbonate of soda is added as long as any precipitation is produced. The liquid contains the triple salt of platina and soda, and muriatic acid, with a little iridium; by exposing it for some time to the air, the iridium separates. The liquid is lastly precipitated by muriate of ammonia; the precipitate, if it contain no iridium, is of a golden yellow colour, and, reduced by heat, affords platina free from that metal, and, according to Descostils, in its state of greatest known purity*.

Platina, in the dense or massive state into which it is brought by the usual processes, is of a white colour, approaching to that of silver, but less pure, and accompanied with less lustre. In hardness, it is superior to the greater number of metals, and has been supposed to be

* *Memoires de la Societ  d'Arcueil*, t. i. p. 370.

exceeded only by manganese and iron. This hardness renders it difficult to estimate its malleability ; it can be beat, however, into very thin plates : its ductility is very considerable, and, according to the experiments of Guyton *, is inferior only to that of iron and of copper. In specific gravity it exceeds all the metals, and it is of course the heaviest substance with which we are acquainted. The specific gravity has been estimated so high as 23,000, or even 24,000 ; according to Borda, it is 20,980 ; and according to Guyton, that of platina in wire is 20,847 ; but it will no doubt vary somewhat from having been more or less strongly hammered, and probably also according to the process by which it has been purified, so as to have been freed more or less completely from the alloy of the other metals naturally associated with it, or frequently combined with it in the usual processes.

Platina expands less by heat than the greater number of metals do. According to Borda, the expansion is equal to $\frac{1}{71000}$ for each degree of Reaumur, or $\frac{1}{110000}$ for each degree of the centigrade scale. According to Dr Wollaston, the expansion of steel between the freezing and boiling points of water being estimated at twelve parts, that of platina is equal only to nine. Platina, according to Dr Wollaston's experiments, is also a less perfect conductor of caloric than the other metals. Slips of silver, copper, and platina, being coated with wax, and one extremity being raised to a red heat, while the coating was melted on the silver to the distance of $3\frac{1}{4}$ inches, and on the

* Annales de Chimie, tom. xxv. p. 9.

copper to that of $2\frac{1}{2}$, it was melted on the platina the length only of 1 inch *.

This metal, in relation to caloric, possesses a property peculiar to it and iron, that of *welding* as it is termed, or softening at a temperature much below that which is requisite for its fusion ; so that if in this state two pieces of it are compressed or beat, they may be united firmly.

Platina is one of the least fusible of the metals. The most intense heat which can be raised in a furnace, has been supposed insufficient to melt it alone : hence Guyton estimates its fusing point as beyond 160° of Wedgwood's pyrometer, or the extremity of the scale ; while that of manganese is not higher than 160, and that of iron is estimated at only 130. Accordingly, Messrs Rose and Gehlen found, that in exposing platina to the intense heat in the furnace of the porcelain manufactory at Berlin, they could not fuse it, though the temperature was beyond that at which the pyrometrical pieces of Wedgwood cease to contract, and of course to afford any indication †. Yet Mr Willis had before melted it, by exposing it to the heat of a wind furnace, imbedded merely in charcoal powder, and concluded that it can be brought into perfect fusion at 150 of Wedgwood ‡. When fluxes are employed, its fusion may be effected more easily. Guyton succeeded in melting it in small quantities, by exposing it to the heat of a blast furnace in a crucible with a flux composed of eight parts of pounded glass, one of

* Philosophical Transactions, 1805.

† Nicholson's Journal, vol. xi. p. 166.

‡ Manchester Memoirs, vol. iii. p. 467.

calcined borax, and half a part of charcoal* ; and Mr Chenevix found it to melt in a crucible lined with charcoal powder, by the aid of borax alone, the crucible being exposed to the heat of a forge. The metal without any flux is melted also in the focus of a very powerful burning lens, and in the heat excited in burning charcoal by a stream of oxygen gas.

Platina does not combine easily with oxygen. Its lustre is not diminished by long exposure to the air, nor even when it is at the same time exposed to a high heat. The grains of crude platina, by an intense heat, become dull and change colour ; but this may be owing to the presence of alloy. A wire of platina can be oxidized, however, by the electric discharge. Van Marum found, that a discharge transmitted over it from a powerful battery dissipated it in vapour, which condensed into a grey powder, this being accompanied with a flash of light. Mr Cuthbertson observed a similar production of oxide of a dark colour, and found the oxygen of the air to be abstracted. Mr Tennant, some years ago, observed, that platina heated with nitre was oxidized, and the oxide combined with the alkali. On dissolving the saline matter, the greater part of the oxide was precipitated in combination with a portion of alkali, forming a substance soluble in acids †.

Mr Chenevix, in the course of his researches on palladium, sought to determine the degrees of oxidizement of which platina is susceptible. Having dissolved reduced platina in nitro-muriatic acid, he precipitated it by

* Fourcroy, vol. vi. p. 560.

† Philosophical Transactions, 1797.

lime, redissolved the precipitate in nitric acid, and evaporated the solution to dryness: he thus obtained a sub-nitrate of platina, which was exposed in a crucible to a heat capable of expelling the nitric acid. The oxide remained alone. On exposing this to a heat inferior to that capable of melting silver, it was reduced, and appeared with metallic lustre. From this experiment, he inferred that this oxide, which, from its colour, may be named yellow oxide of platina, consists of 87 of metal, and 13 of oxygen. But Mr Chenevix likewise observed, that in its reduction it became of a green colour, and remained so for some time, denoting an inferior degree of oxidization. This green oxide, he supposes, contains about seven parts of oxygen in 100 *.

Platina, from its weak attraction to oxygen, is acted on by none of the acids, the oxymuriatic and nitro-muriatic excepted. Sulphuric acid, in its concentrated state, boiled on it, does not alter it. Nitric acid boiled on it does not change its lustre. Muriatic acid is equally inactive with regard to it. Oxymuriatic acid takes it up slowly, and in small quantity. Nitro-muriatic acid dissolves it with facility, especially when assisted by a moderate heat; the muriatic acid aiding the affinity of the platina to oxygen, so as to enable it to decompose the nitric, and, combining with the oxide, forming a muriate of platina. It is obvious, that a certain proportion of the two acids will answer best for the solution, as much nitric being requisite as will afford the necessary proportion of oxygen to the metal, and as much muriatic acid as will combine with

* Philosophical Transactions, 1803, p. 314.

the oxide. Proust has made experiments on this subject, and has found, that instead of equal parts of the two acids, three parts of muriatic acid to one of nitric acid ought to be taken, this dissolving the largest proportion of platina *. The solution is accompanied with a disengagement of nitric oxide, and nitrous acid vapour, with a smell of oxymuriatic acid ; and as it proceeds, a black powder is deposited, which is in part re-dissolved, as it diminishes in quantity if not removed as it is precipitated. This, as has been already remarked, consists partly of oxide of iridium, which, though by itself sparingly soluble in nitro-muriatic acid, becomes more soluble from the reciprocal action of platina, and partly, according to Mr Tennant, of oxide of osmium. It is precipitated in the solution, not only of native platina, but also in that of platina purified according to the common processes.

This solution, when concentrated, is of a deep reddish brown colour, and by evaporation affords crystals of the same colour, but of various shades, according to the state of the solution. The dark colour, we now know from the experiments of Descostils and Vauquelin, arises from the presence of a portion of iridium.

The same substance communicates a deep colour to the precipitates, which the alkalis occasion in the solution of platina in nitro-muriatic acid. The phenomena with regard to these always appeared to be singular and complicated ; and it is only in consequence of our lately acquired knowledge of platina, and the metals naturally associated with it, that they can be understood.

* Philosophical Magazine, vol. xi. p. 122.

If potassa be added to the solution of platina, in a short time small octaedral crystals of a red colour are deposited; if, after this, the addition of the alkali be continued, a yellow spongy powder is deposited, insoluble in water. No precipitation is produced, according to Margraaf and Lewis, by soda, in the solution of muriate of platina; but Bergman found, that by adding it in sufficient quantity, a spongy yellow precipitate was thrown down. Ammonia gives likewise a precipitate in crystalline grains, which, when closely examined, are of an octaedral form, of a red or reddish yellow colour; and when added in larger quantity, another precipitate, in the form of a yellow powder.

In all these precipitations, the pure oxide of platina is not thrown down; it has always a tendency to form triple salts, by uniting with a portion of the acid and the alkali; and the precipitates above described are combinations of this nature; into which also, as is immediately to be stated, oxide of iridium enters in greater or less quantity. By exposing that with ammonia to a sufficient heat, the ammonia, and the muriatic acid, partly in the state of oxy-muriatic acid from receiving the oxygen of the oxide, are disengaged, and the platina is reduced. The muriate of potassa and platina, and that of ammonia and platina, are of a yellow colour, and form small octaedral crystals, sparingly soluble in water*. The muriate of platina and soda is soluble and crystallizable, the figures of its crystals being prismatic or tabular†. Both it and the salt with potassa are reduced by heat.

* Philosophical Transactions, 1804, p. 427.

† Journal de Physique, tom. lvii. p. 389.

From this tendency to form ternary combinations, the same effects are produced on the solutions of platina by several of the neutral salts as well as by the alkalis. Thus sulphate, nitrate, or muriate of potassa, throws down a crystalline precipitate*, and ammoniacal salts equally occasion a precipitation.

The effect of muriate of ammonia, in producing a precipitate in the solution of platina in muriatic acid, was first observed by Lewis, and being a striking property of this metal, has always engaged the attention of those chemists who have examined its chemical actions, especially as it presents some singular results. These have only been elucidated by the late discoveries with regard to the metals naturally associated with platina; and it was indeed, in a great measure, from an accurate investigation of them that these discoveries were made.

It was always known, that by adding, in successive portions, a concentrated solution of muriate of ammonia to a solution of platina in nitro-muriatic acid, precipitates of different colours might be successively obtained. At first, when a certain quantity of the solution of muriate of ammonia has been added, the precipitate which is formed is of a *yellow* colour: if the liquor above it, which is still of a reddish-brown colour, be poured off, and muriate of ammonia added to it, a precipitate is thrown down of a *dark-red* colour.

These precipitates were supposed to differ from each other principally in the state of oxidizement, the one containing the platina more highly oxidized than the other.

* Bergman's Essays, vol. ii. p. 169.

From the experiments, however, of Descostils and Vauquelin, it appears, that the difference between them is more important, and that the one, the yellow precipitate, consists principally of oxide of platina combined with a portion of ammonia and muriatic acid ; while the other, the red precipitate, consists principally of the oxide of the metal which Mr Tennant has since named Iridium, in a similar state of ternary combination.

Descostils took equal quantities of these two precipitates, and dissolved them separately in equal quantities of water, employing the requisite proportion of water for this purpose. The solution of the yellow precipitate was of a golden yellow colour ; that of the other of an orange-red. To prove that the red precipitate did not consist merely of platina in a higher state of oxidizement, he attempted to transfer oxygen to the yellow salt, by means of nitric, oxymuriatic, and nitro-muriatic acids ; but this failed : the colour of the salt, though in some cases a little heightened, remained yellow as before. It is singular, however, that the red precipitate passes to a yellow by the action of substances capable of de-oxidizing it, as by adding to its solution green sulphate of iron, or sulphurous acid ; but what at once proves that this is not analogous to the other yellow precipitate, is, that it immediately recovers its red colour by boiling in nitric acid. Other important differences were found to exist between them. Equal quantities of the two precipitates reduced by heat, give unequal residues ; that of the red precipitate being 0.44 of its weight ; that of the yellow only about 0.425. If the metal, reduced from the yellow precipitate by heat, be exposed to the action of nitro-muriatic acid, it dis-

solves with facility; and muriate of ammonia added to its solution, produces a yellow precipitate. The metal reduced from the red precipitate is differently affected. Whatever quantity of nitro-muriatic acid be employed, there remains always a portion undissolved, which, in the progress of the action exerted by the acid, assumes the appearance of a black powder; and the solution gives, with muriate of ammonia, a precipitate of a red colour, even somewhat more intense than that of the original precipitate.

Descostils had likewise observed, that the more of the black powder which usually separates during the solution of crude platina in nitro-muriatic acid, had been dissolved, the colour of the red precipitate thrown down from the solution was more intense. He found likewise, that this black powder itself, dissolved in a nitro-muriatic acid containing a large proportion of nitric acid, afforded a dark-coloured solution, which gave also a very dark precipitate by muriate of ammonia. By exposing a portion of the metal, reduced by heat from the red precipitate thrown down from the solution of platina, to a strong heat in a porcelain tube with hyper-oxymuriate of potassa, he obtained, by sublimation, a quantity of the blue oxide, which he found may be obtained in small quantity by sublimation from crude platina alone. And by adding to the red precipitate a solution of carbonate of soda, so as to dissolve it, on exposing this to the air, or to the action of oxymuriatic acid, or on evaporating it, a green substance is deposited, which, by heating with borax, may be reduced to a metal, that, exposed to heat in a porcelain retort, gives the blue oxide, or, dissolved in nitro-muriatic acid, affords the dark-coloured solution and

precipitate. The yellow precipitate, submitted to the same process, affords none of this matter, or, at farthest, in some cases a very minute quantity.

These experiments leave no room to doubt, that the dark-coloured precipitates obtained from the solution of platina, differ essentially from the yellow; that they depend on the same matter which separates during the solution of crude platina, under the form of a black powder, and which farther investigations have shewn to be a peculiar metal; and that the yellow precipitate is that which is obtained from muriate of platina. To this, however, a portion of the other metal, iridium, may generally adhere; and it appears, that in the red precipitate there is always a portion of platina present *. This may be separated from it, by adding to its solution sulphuretted hydrogen, which precipitates the platina under the form of a brown deposit, while the other metal remains in solution. The same separation was obtained, by adding to the solution of the red precipitate a quantity of alcohol, with a portion of pure soda or potassa; the temperature rises, and the platina is quickly reduced †.

These results have been confirmed by the experiments of Fourcroy and Vauquelin. By evaporation of the solution of platina in muriatic acid, to disengage the excess of acid, they obtained the muriate of platina in long prisms of a reddish-brown colour. When dissolved in water, this gave the yellow precipitate on the first addition of ammonia: the liquor being poured off, and eva-

* Journal de Physique, tom. lvii. p. 386-7-8-9.

† Journal de Physique, tom. lvii. p. 392-3.

porated, gave a salt of a lively red colour, and formed a solution of a similar colour. Reduced by heat, its solution in nitro-muriatic acid afforded a red precipitate on the addition of muriate of ammonia. They observed too, that of solutions of platina prepared by adding successively portions of nitro-muriatic acid to the metal, and pouring them off as they appeared to be saturated, the first solution gave, by muriate of ammonia, a precipitate of a yellow colour, inclining to orange, while the second and third solutions gave a precipitate of a lively red. And they found, that the black powder, deposited during the action of nitro-muriatic acid on platina, dissolved by itself, gave by muriate of ammonia a very deep red precipitate; and, added in very small quantity to the solution of pure platina, which gave only a yellow precipitate with that salt, gave it the property of precipitating red.

They submitted also to examination, the yellow and red precipitates obtained from the solution of platina, and, in particular, reduced both by exposure to heat. The metal obtained from the yellow precipitate was less white, and less heavy, than that from the red precipitate. It dissolved with great facility in nitro-muriatic acid, and scarcely gave an appreciable trace of any insoluble deposite or powder; that from the red precipitate likewise dissolved easily, but it deposited during the solution a greater quantity of black powder, the solution was of a deeper colour, and gave a red precipitate with muriate of ammonia, while the solution of the other gave a yellow precipitate. Pure potassa added to the former, precipitated a greenish-coloured matter, while, added to the solution of the yellow salt, it had no such effect.

This green matter, when dissolved in an acid, formed a liquid of the same colour, which, added to the solution of pure platina, did not communicate to it the property of forming a red precipitate on the addition of muriate of ammonia; but if the green matter were boiled in the acid, the colour changed, the liquid became of a deep red, and then acquired the power of precipitating the solution of platina red, on the addition of an ammoniacal salt. This proves that this substance must be in a certain degree of oxidizement to form this precipitate*.

These experiments accord with those of Descostils, and prove, that the red-coloured precipitates from platina contain a foreign metal, to which they owe their distinctive properties; and that the yellow precipitate is that which platina, apart from this metal, gives, by the action of muriate of ammonia; this yellow precipitate being a ternary combination of oxide of platina, ammonia, and muriatic acid. They also prove, that platina can be obtained free from this metal, only by reducing the yellow precipitate. Yet even with this precaution, I may observe, it will not be obtained perfectly pure, at least if we admit palladium as a distinct metal; for it is dissolved by nitromuriatic acid, and precipitated by muriate of ammonia.

The solution of muriate of platina is decomposed by several of the metallic salts. Muriate of tin is the most delicate test of it; a solution of the platina so pale as hardly to be distinguished from water, assuming a bright red colour, by a single drop of the recent solution of tin in muriatic acid†. Several of the metals also precipitate

* *Annales de Chimie*, tom. xlix. p. 204-13.

† *Philosophical Transactions*, 1803, p. 315.

the platina more or less de-oxidized. It is not precipitated by prussic acid, or the prussiates.

The other salts of platina are imperfectly known. They may be formed by dissolving the precipitate from the solution in nitro-muriatic acid by lime, in the acid with which it is intended to combine the platina. The experiment would require to be conducted, however, so as to guard against the alloy of foreign metals with the platina, which has not yet been accurately done. Mr Chenevix inferred, from experiments which are liable to this objection, that the insoluble sulphate of platina consists of 54.5 of oxide, and 45.5 of acid and water; the insoluble muriate of 70 of oxide, and 30 of acid and water, and the subnitrate of 89 of oxide and 11 of acid and water*.

The muriate of platina and ammonia decomposed by potassa, affords a precipitate possessed of some degree of fulminating power. Vauquelin and Fourcroy, who observed this, regard it as a compound of the oxides of platina and iridium with ammonia†.

Platina and sulphur do not directly combine together, their mutual affinity being counteracted by the cohesion of the metal, and volatility of the sulphur. It is dissolved, however, by the alkaline sulphurets; and sulphuretted hydrogen, added to its solution in nitro-muriatic acid, occasions a precipitation.

It unites with phosphorus, as Pelletier ascertained, either by projecting small pieces of phosphorus on the platina, raised to a red heat in a crucible, or by exposing to

* Philosophical Transactions, 1803, p. 315.

† Annales de Chimie, tom. xlix. p. 179. 212.

a strong heat a mixture of equal parts of platina and concrete phosphoric acid, with the addition of one-eighth of the weight of the mixture of charcoal powder. The phosphuret of platina, he found to be of a silvery white colour, very brittle, and so hard as to give sparks with steel. It is much more fusible than the metal alone: exposed to a strong fire, the phosphorus is expelled; and in this way Pelletier, as already remarked, endeavoured to obtain pure platina in a convenient form.

Platina unites with the greater number of the metals. The whole of these combinations, however, would require to be again submitted to examination, as they have not hitherto been obtained from pure platina; and even small quantities of the foreign metals associated with it, may have important effects on the properties of these alloys. In the experiments of Mr Hatchet, platina, purified by precipitation by muriate of ammonia, was added to gold, in the proportion of about one-fifteenth of the gold, and they were combined by fusion: the metal was of a yellowish white colour, like tarnished silver, highly ductile, and also elastic, so much so, that Mr Hatchet supposed it might be advantageously employed for the springs of watches, &c. Its specific gravity was 19.013; that of the platina in its loose state having been 18.717. As platina, by its alloy with gold, diminishes neither its specific gravity nor ductility, the Spanish government, on the supposition that it might be employed to adulterate gold, prohibited its importation into Europe; but the adulteration could not be practised to any extent, from the platina debasing so much the colour of the gold.

From an experiment by Guyton *, it appears, that when the alloy does not contain more than 0.155 of platina, the alteration of colour is such, that it does not even present that of gold of the palest colour; and were the fraud attempted, it is easily discovered by chemical tests, particularly by the precipitation of the platina by muriate of ammonia. The alloy with silver is of a dull colour, and is harder than pure silver. With quicksilver, platina, it was supposed, would not combine; and in its dense state, the combination is not easily effected. Guyton has shewn, however, that even a plate of platina is rendered brittle, and increases in weight, by being kept immersed in boiling quicksilver †. And the process of Moussin Poushkin to obtain pure platina, already given, proves, that when the platina is in that loose spongy state in which it is obtained when its precipitates are reduced by heat, it may be amalgamated without difficulty.

Platina derives value from its great hardness and infusibility, and from not being liable to be affected by air, water, or indeed the greater number of chemical agents. From these qualities, it is in particular adapted to the construction of chemical vessels, as crucibles, evaporating basons, wire for galvanic experiments, &c. The difficulty of constructing these, from the infusibility of the metal, is an obstacle to their introduction, and has been only imperfectly obviated, by alloying the platina with arsenic or quicksilver, casting or forging the metal into the requisite shape, and afterwards freeing the platina

* Annales de Chimie, tom. xlvii. p. 301.

† Annales de Chimie, tom. xxv. p. 12.

from the alloy, by the application of heat. These vessels, too, have the disadvantage of being eroded by some chemical agents, as the fixed alkalis, and even some of the neutral salts. Platina has been used, alloyed with a portion of copper and arsenic, in the construction of mirrors for reflecting telescopes; a purpose to which it is well adapted, from giving a single image, from being susceptible of a very high polish from the density of this alloy, and from not tarnishing on exposure to the air. Guyton has employed this metal, too, from its infusibility, in the construction of a pyrometer. From its property of expanding less by heat than the other metals, it was selected by the French philosophers for constructing the rules or scales employed to measure the base of the chain of triangles, from which they estimated an arc of the meridian in France, on which they founded their lineal measures. From the same property it is better adapted than any other metal, for making the pendulum-spring of watches. Mr Scott, who has made this application of it, found that when a coil of it is placed on the surface of a flat piece of metal, making one end of the spring fast, and marking exactly the other extremity, no expansion is visible when heat is applied.

It has been proposed to cover copper-vessels with platina. The method is, to reduce the precipitate, obtained by muriate of ammonia from its solution in nitro-muriatic acid; the spongy metallic matter is triturated in a heated mortar with five parts of quicksilver, by which an amalgam is formed: this is applied to the surface of the clean copper, and the quicksilver is volatilized by heat, which at the same time favours the adhesion of the

platina to the copper. Mr Stoddart has stated also, that brass or steel may be covered with platina, by the same process as that employed in covering steel with gold, already described;—adding sulphuric ether to the solution of platina, removing the ethereal solution of the muriate of platina from the acid beneath, and dipping the polished steel or brass into this ethereal solution *.

Platina has been applied to porcelain-painting by Klaproth. Gold and silver had been the only metals applied to this use, being adapted to it from their not being oxidized by heat, and from their density, in consequence of which they cover completely the surface to which they are applied. Silver, however, is liable to tarnish, and hence is seldom used. Klaproth found that platina has not this inconvenience, and might therefore be introduced to diversify the painting with gold. His method, which succeeded on trial, was to reduce by a low red heat the precipitate of platina from its solution by muriate of ammonia: it is thus obtained in the form of a soft powder, which is mixed with the flux used for porcelain gilding, and applied with a brush to the porcelain: it is then burnt in by the requisite heat under a muffle, and burnished. The colour is silver-white, inclining to steel-grey; and if the platina be mixed in various proportions with gold, numerous shades of colour may be obtained †.

* Nicholson's Journal, vol. xi. p. 283.

† Philosophical Magazine, vol. xvii. p. 136.

CHAP. IV.

IRIDIUM.

OF the foreign metals associated with platina, and the history of which may next be given, Iridium is that which appears to be present in the largest quantity, which is obtained in the least indirect manner, and the claims of which, to be arranged as a distinct metal, are, from these circumstances, least problematical.

It has already been observed, that it constitutes the principal part of the black powder which is deposited during the solution of crude platina in nitro-muriatic acid, though a portion of it, in consequence partly of its own solubility, partly of the reciprocal action of the platina, is dissolved at the same time, and communicates to the solution, and the salts and precipitates which that solution affords, a red colour. It may hence be obtained, either from the black powder, or from the precipitate thrown down from the solution by muriate of ammonia. There are some varieties of native platina, in which it appears to exist in larger proportion than in others. In what has been named by Proust, Black Platina, it is present in considerable quantity *.

Descostils, though he traced the operation of this metal in giving the red colour to the salts of platina, and obtained it apart in the state of an oxide, and even reduced

* *Annales de Chimie*, tom. xlix. p. 177. 202.

this oxide, by exposure to heat with borax and with a small quantity of oil, to the metallic state, did not examine many of its properties in this state. This was done by Mr Tennant, and by Fourcroy and Vauquelin.

Vauquelin operated on the black powder, which is deposited during the solution of crude platina in nitro-muriatic acid. This substance heated alone before the blow-pipe did not melt, but it lost its black colour, and became white, acquiring also a metallic lustre; fused with borax, it is reduced into white metallic scales: and melted with twice its weight of pure potassa, it formed with water a solution of an orange-yellow colour, which became of a reddish brown by the addition of nitric acid; was precipitated of a reddish brown by the solution of silver, and of a dull red by the solution of quicksilver*. Vauquelin inferred from these facts, that it contained, with the new metal, a portion of chrome: but of this Mr Tennant could not by any test discover any trace; and the metallic oxide in combination with the alkali he regards as a new metal;—that to which he has given the name of Osmium, and which, in the property of communicating vivid colours to its combinations, resembles chrome. On adding to the solution of this alkaline combination a solution of lead, he found that a pale or buff coloured precipitate was formed, and not the bright yellow which chrome gives. With regard to this, however, there may still be some doubt, as in subsequent experiments, Vauquelin affirms†, that when the alkali of this solution was saturated with nitric acid, it gave, with nitrate of lead, a precipitate of a very

* Annales de Chimie, tom. xlix. p. 198. † Ibid. p. 220 3.

pure yellow colour ; which, melted with borax, gave an emerald green colour, with nitrate of silver, a lively carmine red ; and when the solution thus saturated was evaporated, among the crystals of nitrate of potassa were crystals of a ruby-red colour, supposed to be acid of chrome.

Whether chrome be contained in small quantity in this black powder or not, Vauquelin found by other experiments, of which an account has been already given under the history of platina, that the powder consists principally of the metal which is the subject of the present chapter : and the following is the process which he followed to procure it pure. The powder deposited during the solution of the platina in nitro-muriatic acid, was exposed to heat with three times its weight of potassa ; then washed with water, when it formed a solution of an orange yellow colour ; on the quantity of matter undissolved by the alkali, and which had assumed a green colour, muriatic acid was digested, and a solution was obtained of a deep green, which became red by boiling. These alternate actions of the acid and alkali, were repeated until the whole of the powder was dissolved. It was afterwards found, that to fuse the black powder with an equal weight of potassa answered better, as to be rendered soluble in the acid, it appeared to require to be oxidized by the atmospheric air, and this quantity of alkali presented less obstacle to the absorption of oxygen ; so that by repeating the operation twice or thrice with this proportion, the whole powder was decomposed.

The green colour of the muriatic solution appeared to Fourcroy and Vauquelin to depend on the presence of iron. The oxide and muriate of the new metal are of a

blue colour, which mixed with the yellow muriate of iron produced the green ; and accordingly they found, that in proportion as the alternate applications of the acid and alkali were repeated, the green colour became weaker from the iron being removed, and at the end, the solution in the acid was of a pure and rich blue.

To separate this iron, and obtain the other metal pure, the solutions in muriatic acid from a given quantity of the black powder, treated in the preceding method, were mixed together, and evaporated to dryness. The silex retained in solution was thus rendered insoluble : the solid matter was redissolved in water, and the solution filtered and made to boil ; it thus acquired a fine red colour. Plates of zinc and a little muriatic acid were put into the liquor ; in a short time it became green, and then blue, from the iron, in consequence of the action of the zinc, passing to the minimum of oxidizement, while at the same time the other metal was precipitated ; in consequence of this, the liquid became turbid, and deposited abundantly floculi of a black colour, and much lustre. This precipitate being allowed to subside, and the liquor above poured off, was washed with water, and, lastly, with a little muriatic acid, to carry off any iron that might adhere to it : in drying it with a gentle heat, it became white, and assumed a perfect metallic lustre. Another easy process, which these chemists found to succeed, was, to treat the dry matter, obtained by the evaporation with a moderate heat of the muriatic solutions, with alkohol : this dissolved the whole of the muriate of iron ; and the muriate of iridium remained under the form of a red powder, which might be de-

composed by a slight calcination in a silver or platina bason*.

The process which Mr Tennant followed to obtain this metal was similar. A quantity of the black powder was put into a crucible of silver, with a large proportion of pure soda, and kept at a red heat. The alkali dissolved in water had acquired a deep orange or brownish yellow colour, but much of the powder remained undissolved. This powder digested in muriatic acid, gave a dark blue solution, which afterwards became of a dusky olive green; and, finally, by continuing the heat, of a deep red colour. Part of the powder being yet undissolved by the acid, was heated as before with the alkali, and by the alternate action of the alkali and acid, the whole appeared capable of solution. At each operation, a portion of silex, which appeared to have been chemically combined in the powder, was taken up by the alkali.

The alkaline solution, according to Mr Tennant, contains the oxide of a new metal,—that to which he gave the name of Osmium. The acid solution contains both metals, but principally iridium. To obtain it, the method he employed was to produce, by slow evaporation, a crystallized mass. This, on being dried, and again dissolved in water, afforded by evaporation octaedral crystals; which, dissolved in water, gave a deep red-coloured solution. The iridium may be obtained from these crystals, in a pure state, merely by exposing them to heat, which expels the oxygen and the muriatic acid: it appeared of a

* *Annales de Chimie*, tom. 1, p. 16-17 18.

white colour, but was not capable of being melted by any degree of heat that could be applied*.

Though Mr Tennant could not procure this metal in its proper state of aggregation, from its great infusibility, it was obtained in this state, both in the experiments of Descostils and those of Fourcroy and Vauquelin. They describe it as being of a white colour, brittle, and very easily pulverized; and the latter chemists ascribe to it the hardness and rigidity of platina,—qualities which do not appear in the same degree when the platina is freed from it. It appears to be capable of being volatilized by heat, as, when precipitated from its solutions by zinc, and heated strongly before the blowpipe, it gives a white smoke, and disappears entirely; and in fusing it with borax, it loses in weight.

It is not difficult of oxidizement. By applying a very strong heat to crude platina in an earthen retort, Descostils obtained a sublimate of a blue colour, which he regarded as an oxide of this metal. And Fourcroy and Vauquelin have remarked, that the pure metal, calcined with an equal quantity of potassa, suffers oxidizement from the atmospheric air, and forms with the alkali a green-coloured mass. If diluted with water, the potassa is dissolved, carrying with it a portion of the oxide, which communicates to it a red colour, and which may be separated in red floculi, by the addition of an acid. Muriatic acid added to the undissolved matter, dissolves a part of it, and acquires a green colour.

In these combinations, this metal is susceptible of dif-

* Philosophical Transactions, 1804, p. 413-4-5.

ferent degrees of oxidizement, which are rendered evident by the different colours they assume. The muriatic solution, for example, is at first of a green colour, which was supposed to be owing to the presence of iron. But although this metal is sometimes present, especially in the liquid, which is formed by the affusion of the first portion of muriatic acid on the powder calcined with the alkali, the green solution can be obtained free from it, as in the last of the solutions obtained by the action of successive portions of the acid, or by dissolving in the pure acid the oxide precipitated from the alkaline solution. This solution, which is of a very deep green, becomes blue by farther dilution with water,—a proof that the green colour is not owing to iron; and when heated it becomes red. Substances capable of de-oxidizing it, as the metals, or the solution of green sulphate of iron, destroy the red colour, and produce a green or blue.

No unmixed acid attacks this metal: even the nitro-muriatic acid has a weak action upon it, and dissolves with the assistance of heat a very small portion: alloyed with platina, it is more soluble. It communicates to the acid a red colour, which, as the solution is evaporated, is changed to a pure blue; the red re-appears when the evaporation is carried to perfect dryness.

When the metal has been oxidized by the aid of an alkali and atmospheric air, or has been precipitated in the state of an oxide from its solution in nitro-muriatic acid, it dissolves easily in the mineral acids: the sulphuric and muriatic acids become green or blue, according as they are more or less diluted with water: the nitric acid, when concentrated, always forms a red solution. These so-

lutions are precipitated by the alkalis of the same colour ; those which are red, giving a red precipitate ; those which are green, a green ; the former is re-dissolved by an excess of alkali, the latter is not.

When these solutions are free from iron, they suffer no alteration from prussiate of potassa. The tincture of galls, aided by a small quantity of alkali, causes the liquor to assume a violet colour, and at length forms a reddish-brown precipitate. According to Mr Tennant, the solution of the crystallized muriate of iridium, which was of a deep red colour, was rendered colourless without forming any precipitate, by infusion of galls, prussiate of potassa, muriate of tin, and carbonate of potassa. Sulphate of iron, according to Vauquelin, renders the red solution of iridium at first violet, afterwards green, and causes by the aid of heat a deposition of a black powder. Sulphuretted hydrogen, and the hydro-sulphurets, destroy the colour of the solution, and, when heat is applied, precipitate a powder of a brownish-black colour. The greater number of the metals cause the red colour of the solution to disappear, and throw down a precipitate of a dark colour, according to Tennant ; and according to Vauquelin, one consisting of green flocculi.

These facts, as Vauquelin remarks, prove that this metal has no strong affinity to oxygen, and is easily deprived of it by a number of other substances. They prove also, that it is susceptible of different degrees of oxidizement, whence different colours arise.

Mr Tennant was unable to combine this metal with sulphur. It did not unite with arsenic. Lead combines easily with it, but it is separated by cupellation. Cop-

per forms with it a malleable alloy : silver also may be combined with it, and remains malleable, nor is the iridium separated from it by cupellation ; it appeared, however, to be not perfectly combined with the silver, but rather diffused through its substance in the state of a powder. Gold alloyed with it is malleable, nor is the colour much different from that of pure gold. The iridium is not separated by cupellation : from the alloy, both of silver and gold, it is separated by solution, remaining in the form of a black powder, while these metals are dissolved.

Whether this be a distinct metal, must be determined by future research. Mr Chenevix has clearly shewn, that one metal may, by combination with another, modify, not only its physical properties, but the phenomena exhibited by it in chemical actions ; and an alloy of this nature, examined in small quantities, and under circumstances in which various metals may be present, may appear as a distinct metal. Iridium, in many of its properties, bears a resemblance to platina. In others of them, it is justly observed by Mr Hume, that it is analogous to tungsten, particularly in its difficult solubility in acids, the solubility of its oxides in alkalis, the vivid and transitory colours which it assumes in its solutions, and the communication of a blue colour to water by the oxide of each of these metals *. It obviously requires, therefore, to be submitted to a more strict examination.

* Philosophical Magazine, vol. xix. p. 31.

CHAP. V.

OSMIUM.

IN the account of Iridium it has been stated, that when the black powder deposited during the solution of crude platina in nitro-muriatic acid is fused with soda or potassa, while much of it remains undissolved, a portion enters into combination with the alkali, forming with it a compound that is soluble in water. This matter, that is dissolved by the soda, has been examined by Mr Tennant, and has been considered by him as the oxide of a new metal, which from a peculiar property it has of forming an oxide having a strong smell, he has named OSMIUM.

The whole of the oxide of osmium is not, by the above process, extracted from the black powder; the repeated and alternate applications of soda or potassa, and of muriatic acid, are required; the acid dissolving principally the iridium, the alkali, the osmium. The oxide of osmium is easily detached from its combination with the alkali by any acid, and, what is a very singular property, may be obtained in solution with water by distillation. The sulphuric acid, as being the least volatile, answers best for this purpose, though, as even a little of it is liable to pass over, a second slow distillation is required to obtain the oxide perfectly free from it. The solution thus obtained is without colour, has a sweetish taste, and a pungent and peculiar smell. Paper stained blue with violets was not reddened by it, but, exposed

to the vapour arising from it in a phial, lost much of its blue colour, and inclined to grey.

Another mode by which oxide of osmium is obtained in a concentrated state, is to distil with nitre the black powder procured from platina, with a degree of heat hardly red: there sublimes into the neck of the retort a fluid apparently oily, but which on cooling concretes into a solid, colourless, semi-transparent mass, which is soluble in water. The oxide in this concentrated state stains the skin of a dark colour, which cannot be effaced.

The most striking test of the oxide of osmium, is an infusion of galls, which produces a purple colour, which becomes soon after of a deep vivid blue. It may thus be recognized, when contained even in the solution of iridium; the red colour of the latter being first taken away, on the addition of the infusion of galls, and the purple and blue colour, from the action of the osmium, soon appearing. The solution of oxide of osmium becomes somewhat yellow with pure ammonia, and with carbonate of soda; with lime a bright yellow colour is acquired; by chalk or by magnesia it is not affected. It produces no effect on a solution of platina or gold, but precipitates lead of a yellowish-brown, mercury of a white, and muriate of tin of a brown colour.

Oxide of osmium appears to be easily de-oxidized. It becomes of a black colour with alcohol or ether, and soon separates in the form of black films. It parts, too, with its oxygen to all the metals excepting gold and platina. Silver kept in a solution of it acquires a dark colour, but does not entirely deprive it of smell. Copper, tin, zinc, and phosphorus, quickly produce a black or

grey powder, and deprive the solution of all smell, and of the power of turning galls of a blue colour: this powder consists of the osmium in a metallic state, with the oxide of the metal employed to precipitate it.

On this Mr Tennant founded a process, by which the osmium was obtained in its metallic form. By agitation of the solution of the oxide in water with quicksilver, it soon loses its smell, and the metal combining with the quicksilver forms an amalgam. From this much of the mercury may be separated by pressure through leather; the remaining firm amalgam being exposed to heat, the mercury is distilled off, and a powder is left of a dark grey or blue colour, which is the osmium in its pure state. By exposing it to heat, with the access of air it is oxidized, and evaporates with the usual smell; but if this is prevented, the metal does not appear volatile or very fusible. Being subjected to a strong white heat in a cavity made in a piece of charcoal, it was not melted, nor did it undergo any apparent alteration. When exposed to heat in a similar situation with copper and with gold, it melted with each of these metals, forming alloys which were quite malleable. They were easily dissolved in nitro-muriatic acid, and by distillation afforded the oxide of osmium with the usual properties.

The pure metal, which has been previously heated, does not seem to be acted on by acids, not even by the nitro-muriatic acid. By exposing it to heat in a silver cup with pure alkali, it combined with it, and gave with water the usual yellow solution. And from this, acids separated the oxide of osmium.

These are the properties of this metal, as ascertained

by Mr Tennant its discoverer, by whom only has it been examined *. Fourcroy and Vauquelin, in the course of their experiments observed, indeed, that in lixiviating the substance obtained, by having exposed the black powder deposited from platina to heat with potassa, a vapour exhaled from it, which was pungent and acrid; and that by distillation of the solution, a fluid was obtained, having the same penetrating odour, which stained the skin, gave a blue colour to the corks of the bottles in which it was put, and became of a beautiful blue on the addition of infusion of galls. These phenomena were no doubt owing to the presence of oxide of osmium; but these chemists appear to have considered them as depending on iridium in a peculiar state of oxidizement †.

CHAP. VI.

RHODIUM.

SOME doubt may perhaps be entertained as to the existence, as a distinct metal, of the substance to which Dr Wollaston has given the name of Rhodium, as its properties are not highly characteristic, and as some of those assigned to it are such as might arise from one or other of the preceding new metals in some state of combination. The whole subject, however, relating to the metals associated with platina, must be regarded as in-

* Philosophical Transactions, 1804, p. 416-7-8.

† Annales de Chimie, tom. I. p. 9-14-25.

volved in some obscurity; and it is therefore preferable to await the results of farther investigation, and at present give their history as delivered by their discoverers, instead of submitting to minute discussion experiments which are imperfect. The experiments of Wollaston, with regard to the extraction of rhodium as well as palladium, the other new metal he discovered, have recently been confirmed by Descostils*.

Dr Wollaston remarked, that after the precipitation of the solution of platina in nitro-muriatic acid, by muriate of ammonia, there remain in solution certain metals, which are not thrown down. These are copper and lead, with the two new metals, rhodium and palladium; and the following is the process he gives to separate these, and obtain the rhodium in a pure state.

Crude platina having been exposed to a red heat to expel any mercury, was digested for some time in a small quantity of dilute nitro-muriatic acid, to abstract from it any portion of gold that might be mixed with it. It was then dissolved in nitro-muriatic acid, diluted for the purpose of leaving undissolved as much as possible of the shining powder, and the whole was suffered to remain in a moderate sand-heat till completely saturated. A portion of it, corresponding to 1000 grains of crude platina, was precipitated by a solution of one ounce of muriate of ammonia in hot water. The precipitate obtained was of a yellow colour, and when heated afforded 815 grains of purified platina. In the remaining liquid, to which the water with which the precipitate was washed was added,

* Journal de Physique, tom. lxi. p. 399.

a piece of clean zinc was immersed, and allowed to remain, until no farther action appeared to be exerted on it. The iron contained in the crude platina remained in solution: the other metals had been precipitated in the form of a black powder, estimated to amount to between 40 and 50 grains. This precipitate, which by previous experiments was known to consist of platina, rhodium, palladium, copper, and lead, was digested in very dilute nitric acid, by which the two latter metals were removed. The remainder was digested in nitro-muriatic acid, which dissolved the greater part; the residuum, which was probably iridium, not exceeding $4\frac{1}{2}$ grains. To the solution was added 20 grains of common salt; and when the whole had been evaporated to dryness with a gentle heat, the solid matter, consisting of the triple salts of soda and muriatic acid, with oxide of platina, of palladium, and rhodium, was washed repeatedly with alcohol till it came off nearly colourless. There remained undissolved the triple salt of rhodium, which is thus freed from all metallic impurities. When dissolved in water, and decomposed by zinc, a black powder was obtained, in quantity corresponding to about 4 grains from the 1000 grains of crude platina dissolved. This powder, exposed to heat, continued black; with borax it acquired a white metallic lustre, but appeared infusible by any degree of heat. Like platina, it is rendered fusible by arsenic, as it also is by sulphur: the arsenic, or the sulphur, is expelled by a continuance of the heat; but the metallic button obtained does not become malleable. Its specific gravity, as far as could be ascertained, appeared to exceed 11*.

* Philosophical Transactions, 1804, p. 422.

The solution of the triple salt of muriatic acid, soda, and oxide of rhodium, obtained pure by the preceding process, exhibits the following peculiar phenomena, when submitted to the common re-agents. Muriate of ammonia occasions no precipitation from it; but when a solution of platina is added to the mixture, a precipitate is formed of a yellow colour. Prussiate of potassa occasions no precipitation, neither does hydro-sulphuret of ammonia. Even the carbonate of potassa, of soda, or of ammonia, does not precipitate it; but the pure alkalis throw down a yellow oxide, which is soluble by an excess of alkali.

This oxide Dr Wollaston found to be soluble in every acid that he tried: its solution in muriatic acid did not crystallize on evaporation; the residuum was soluble in alcohol, and of a rose colour. Muriate of ammonia, or of soda, or nitrate of potassa, occasioned no precipitate in it, but formed triple salts, which were not soluble in alcohol. The solution of it in nitric acid also did not crystallize; but the metal was precipitated from it by silver, copper, and other metals.

Rhodium unites with all metals that have been tried, except mercury. With gold or silver it forms very malleable alloys, which are not oxidized by a high degree of heat, but become encrusted with a black oxide when very slowly cooled. The colour of gold is so little altered, that, even when the proportion of rhodium amounts to one-sixth, it is not different from that of fine gold. The alloy is less fusible than gold. In dissolving either the alloy of gold or silver, the rhodium remained untouched, either by nitric or nitro-muriatic acid. But when one

part of rhodium was fused with three parts of bismuth, of copper, or of lead, each of these alloys could be dissolved in a mixture of two parts, by measure of muriatic with one part of nitric acid; and the muriate of rhodium had the same colour and properties as when pure.

CHAP. VII.

PALLADIUM.

THIS is the last of the new metals we have to describe, which have been supposed to exist in native platina. It has already been observed, that it was discovered by Dr Wollaston, who, from the fanciful coincidence of the planet to which the name of Pallas was given having been discovered about the same time, gave it the name of Palladium.

It is obtained by the process already described for procuring rhodium; the triple salts of muriatic acid, and soda, with rhodium, palladium, and platina, remaining in the last stage of that process, previous to the affusion of alcohol. The alcohol is employed to separate these salts, that of rhodium not being soluble in it, while that of palladium is dissolved, with the small portion of muriate of soda and platina which is present. This platina is precipitated from the solution by the addition of muriate of ammonia. To the solution, diluted to prevent any further precipitation of platina, prussiate of potassa is added, which instantly occasions a precipitate of a deep orange colour at first, but afterwards changing to a green, proba-

bly from iron contained in the prussiate. This precipitate dried and heated, leaves a metallic residuum, amounting to about seven grains from the solution of 1000 grains of crude platina. When heated with borax, it communicates a dark brown colour to it, and acquires a bright metallic lustre, but does not fuse before the blowpipe: a little sulphur, however, causes it to melt immediately: from the globule thus obtained, the sulphur is expelled by exposure to the extremity of the flame of the blowpipe, and the palladium remains spongy and malleable*.

Several other processes have since been given by Dr Wollaston to obtain palladium. Thus it differs from platina in not being precipitated from nitro-muriatic acid by nitre, or other salts having potassa for their base; for although a triple salt is formed, it remains dissolved. By dissolving, therefore, one ounce of nitre in five ounces of muriatic acid, a solvent of palladium was obtained, having little power of acting on platina; and by causing this to act on the precipitate which is thrown down by iron from the liquid that remains, after the solution of crude platina has been precipitated by muriate of ammonia, or rather on this precipitate purified by having been dissolved in nitro-muriatic acid, freed from gold by sulphate of iron, and again thrown down by iron, a solution is obtained, from which, by due evaporation, crystals were formed of the compound of oxide of palladium, potassa, and muriatic acid. From this salt, purified by a second crystallization, the metal may be precipitated nearly pure by iron or zinc. A process still more simple and easy, is

* Philosophical Transactions, 1804, p. 426.

to add to a solution of crude platina, whether neutral or not, or whether freed from platina by the muriate of ammonia, a solution of prussiate of mercury : in a short time the solution becomes slightly turbid, and a flocculent precipitate is gradually formed of a yellowish white colour. This consists wholly of prussiate of palladium, and, when heated, yields that metal in a pure state, amounting to about four or five tenths in the hundred, on the quantity of ore dissolved *.

The properties of this metal have been determined partly by Dr Wollaston, and more fully by Mr Chenevix, in the course of the experiments which he undertook to discover its nature †.

It is of a greyish-white colour, and, when polished, of considerable lustre : it is ductile and very malleable ; so that by the flatting-mill it can be reduced into thin slips, which are flexible, but not very elastic. Its fracture is fibrous, and in diverging striæ, shewing a kind of crystalline arrangement. In hardness, it is superior to forged iron. Its specific gravity varies according to its perfect fusion, and as it is more or less porous from hammering or flatting, from 10.9 to 11.8. Dr Wollaston observed, that like platina it is a less perfect conductor of caloric than the other metals ; and is also less expansible, though it is rather more so than platina.

When exposed to a strong heat, its surface tarnishes a little, and becomes blue, but, by increasing the heat, it again becomes bright. At a heat above that necessary

* Philosophical Transactions, 1805, p. 327.

† Ibid, 1803, p. 290.

to melt gold, there is no appearance of fusion even in the thin slips, but, by increasing the heat considerably, its fusion is accomplished.

It does not appear to suffer oxidizement from heat ; on the contrary, its oxides, formed by the action of acids, are reduced.

It is acted on by a number of the acids. Nitric acid acquires from it a beautiful red colour, but the quantity dissolved is extremely small. The action of nitrous acid on it is more rapid and powerful. Sulphuric acid boiled on it, acquires the same red colour, and dissolves a small portion of it. The action of muriatic acid is similar in its results to that of sulphuric acid. Nitro-muriatic acid forms with it a solution of a deep red.

These solutions are decomposed by the alkalis and earths ; precipitates being thrown down, which are generally of a beautiful orange colour : these are partly redissolved if the alkali be added in excess. The sulphate, nitrate, and muriate of potassa or ammonia, produce, as Mr Chenevix observed, a precipitate in the salts of palladium of an orange colour, as well as in those of platina, when they are not in too dilute a solution : according to the observation of Dr Wollaston, the solution requires to be concentrated, as the salts at least with a base of potassa, form ternary compounds with oxide of palladium, which are very soluble. These precipitates are triple salts, and are all much more soluble than the triple salts of platina. They are insoluble in alcohol.

The alkalis act on palladium even in the metallic state. Exposed to the action of potassa in fusion, it loses its brilliancy, and part of its weight, a portion being com-

bined with the alkali. The action of soda is less powerful. Ammonia allowed to remain for some days on palladium, acquires a bluish tinge, and holds a small portion of oxide in solution. In all these cases, Mr Chenevix remarks, the action of the alkali is promoted by the atmospheric air, which affords oxygen to the metal.

The solutions of palladium in the acids are decomposed by a number of the usual re-agents. Recent muriate of tin, gives a dark orange or brown precipitate from the neutralized solutions; or if mixed in such proportion as to remain transparent, changes it to a beautiful emerald green. Green sulphate of iron throws down the palladium in a metallic state. A solution of sulphuretted hydrogen throws down a precipitate of a dark brown colour. Prussiate of potassa causes an olive-coloured precipitate to form; prussiate of mercury, a precipitate of a yellowish-white colour, and, as it does not precipitate platina, is an excellent test of palladium. Dr Wollaston observed, that the precipitate by prussiate of mercury, from the neutral nitrous solution of palladium, detonates, when heated to about 500° of Fahrenheit, with a noise similar to that of gunpowder. Fluoric, arsenic, phosphoric, oxalic, tartaric, citric, and some other acids, together with their salts, it is observed by Mr Chenevix, precipitate some of the solutions of palladium.

All the metals, with the exception of gold, silver, and platina, precipitate palladium from its solution in the metallic state.

Palladium combines readily with sulphur. If raised to a high heat, but such as is not sufficient to melt it; on throwing upon it a little sulphur, it is fused, and remains

in fusion even at a low red heat. The sulphuret is whiter than the metal, and is extremely brittle.

Mr Chenevix did not find that palladium suffered any change of properties from being kept in fusion in a charcoal crucible. It appears therefore to form no combination with carbon.

He found that it could be alloyed with a number of the metals. With gold it formed an alloy of a grey colour, much harder than gold, but less ductile even than the palladium. Its fracture was coarse grained, and its specific gravity 11.079. Alloyed with an equal weight of silver, it gave a compound of a similar colour, hard, and having a specific gravity of 11.290. Equal parts of platina and palladium entered into fusion at a heat not much superior to that capable of fusing palladium alone. The alloy resembled the preceding in colour and hardness; its specific gravity was 15.141. The alloy of palladium, with an equal weight of copper, was more of a yellow colour, and was more hard and brittle. Lead was found to increase the fusibility of palladium, forming an alloy superior to all the former in hardness, but extremely brittle. Its specific gravity was 12.000. With iron, tin, bismuth, and arsenic, it formed alloys hard, and all of them extremely brittle.

In concluding the history of this metal, it is necessary to take notice of the assertion advanced by Mr Chenevix, that it is an alloy of platina and quicksilver. It has already been observed, that it was offered for sale in small quantities, without any thing being made public as to its origin or discovery; and with an imperfect statement of

its properties. It attracted the attention of Mr Chenevix, and, being struck with its peculiar qualities, he engaged in a series of experiments with regard to it *.

It had evidently properties very different from those of any known metal or metallic combination. "Gold and platina," Mr Chenevix remarks, "could scarcely be supposed present in it, as it is in some measure acted on by sulphuric and muriatic acid, and is wholly soluble in nitric acid. Silver is excluded by the effect of muriatic acid on its solutions, as is lead by that of the sulphuric acid. Tin, antimony, bismuth, or tellurium, would have left an insoluble residuum with nitric acid. No traces could be found of any of the acidifiable metals; and iron was looked for with particular care, but in vain. In a word, the precipitation by the metals seems to exclude all those of easier oxidability than mercury; and this we should not suppose to be present, as copper is not in the least whitened when used to precipitate palladium."

The striking similarity of many of the precipitates of palladium with those of platina, induced Mr Chenevix to direct his attention to this metal; and in considering the effects produced by the union of metals with each other, the changes in their properties, and in the affinities they observe, it occurred to him, that from the affinity of platina with some metal easily reduced, both might be reduced to the metallic state by sulphate of iron, although no such effect were produced on either metal when separate. The most likely to succeed, as being most easily reduced after gold, platina, and silver, was mercury. On

* Philosophical Transactions, 1803, p. 290.

pouring a solution of green sulphate of iron into a solution of platina, and into a solution of mercury, no precipitation took place; but on uniting the two liquors, a precipitate resembling that which is formed by green sulphate of iron in palladium, was instantly formed. By exposing this to a strong heat, after repeated trials, a metallic button, not to be distinguished, adds Mr Chenevix, from palladium, was obtained; and thus, not by its analysis, but by a synthetic experiment, he considered it as proved to be an alloy of platina and quicksilver.

The success of the experiment, however, was found by Mr Chenevix himself to be very uncertain. In various arrangements in which these two metals were presented to each other, either no combination took place, or a substance was formed, which, though different from platina, was not palladium. The following he gives as the most successful experiment, which, under the uncertainty that is still in some measure attached to this subject, it may be proper to transcribe: "I dissolved 100 grains of platina in nitro-muriatic acid, and then put in 200 grains of red oxide of mercury, made by nitric acid; but this not being sufficient to saturate the excess of acid, I continued to add more, until it ceased to be dissolved. On the other hand, I prepared some green sulphate of iron, and poured it into a long-necked matrass. I then poured the mixed solution of platina and mercury into the solution of green sulphate of iron, and heated the whole upon a sand bath. In less than half an hour, a copious precipitate was formed; and the inside of the matrass was lined with a thin metallic coat. The liquor was passed through a filtre, which I had weighed; and the preci-

pitate after digestion with muriatic acid, was well washed and dried. When I had collected as much of this as I could, there remained upon the filtre 12 grains; besides which, I had collected 264, in all 276. The supernatant liquor still contained a portion of mercury, and about eight grains of platina. Therefore, the 276 were composed of 92 of platina, and 184 of mercury. From this it appears, that 100 grains of platina can determine the precipitation of near 200 grains of mercury by green sulphate of iron; and that, in this proportion, there is a reciprocity of saturation. The 264 collected from the filtre, were exposed to a low red heat, and were reduced to 144. The 12 of the filtre would have given about seven; therefore, the whole would have been 151. The substance was in the form of a fine powder, and had a metallic lustre. It was then put into a charcoal crucible, and fused into a button. This button weighed 128 grains, and, with the quantity left on the filtre, would have weighed 135. In this 135, there were 92 of platina: therefore it was composed of about two parts of that metal and one of mercury. It was of the specific gravity of 11.2; was wholly soluble in nitric acid; was easily fused by sulphur; was precipitated by green sulphate of iron: in a word, it was not to be distinguished from palladium *."

With every chemist, however, who has made this experiment, it has failed; and though Mr Chenevix, in his observations on this subject †, has shewn, that in some of

* Philosophical Transactions, 1803, p. 300.

† Philosophical Transactions, 1805, p. 104.

these, deviations were made from the strict process, yet the general failure affords a presumption of some error,—a presumption which even follows from Mr Chenevix's own experiments, since, numerous as they were, amounting at least to 1000, he had only four successful operations; nor did this labour lead to any certainty in the investigation, so as to enable us, by the exact repetition of any process, to produce palladium.

As Dr Wollaston has observed, too *, there is an anomaly attending this combination so great, as to afford the greatest reason to doubt of the possibility of palladium being a compound of platina and mercury,—that of the specific gravity of it being 11.8, while that of quicksilver, the lighter of the two metals, is above 13. In chemical combination there may be such a condensation as shall render the specific gravity of the compound greater than the mean specific gravity of its constituent parts; or, even where there is a change of form, it may be more dense than the denser of its ingredients; as, on the other hand, from the peculiar crystalline arrangement into which the new substances may be disposed to pass, or from its change of form, its specific gravity may be inferior to that of the mean. But there is certainly no instance in which the specific gravity of any compound is less than that of its lightest ingredient, as that of palladium would afford, were it a compound of these two metals.

The properties of palladium, it must also be acknowledged, are highly appropriate and characteristic: it can be recovered unaltered from numerous combinations; and

* Philosophical Transactions, 1804, p. 429.

no analytic experiment has appeared to discover its composition. These, as Dr Wollaston has justly observed, appear sufficient to lead us to regard it as a simple metal.

Yet, as Mr Chenevix has remarked *, it is proved by his experiments, confirmed with regard to several of the following facts by the experiments of other chemists who have engaged in this investigation, that platina and mercury act on each other, so as to disguise and modify their respective properties. Platina is not precipitated by sulphate of iron, but this property, one of the most distinctive belonging to palladium, is conferred on it by mercury; the solution of platina, when mixed with a solution of quicksilver, suffering this precipitation, and the platina being thrown down in combination with a portion of the latter metal. In this combination, platina can protect a quantity of mercury from the action of nitric acid, while mercury increases the action of nitro-muriatic acid on platina. And, lastly, a portion of mercury may be combined with platina, so as not to be dissipated by the heat necessary to fuse the compound. These may leave some doubt with regard to this subject: they are at least important results; and they, as well as other facts established by Mr Chenevix, proving the striking effects which arise from the mutual affinities of metals, have given interest to the investigation, independent of the immediate object to which it was directed.

* Philosophical Transactions, 1805, p. 126.

CHAP. VIII.

QUICKSILVER OR MERCURY.

THIS metal is distinguished by its fluidity at any common natural temperature. At 40° or 39° below the commencement of Fahrenheit's scale, it passes to the solid state. It forms the connection between the preceding metals, and those, the history of which is to follow. Like the latter, it can be oxidized by heating it in contact with atmospheric air; like the former, its oxides are reduced by exposure to heat alone, the oxygen being expelled, and the quicksilver returning to the metallic state. Though fluid, it is as perfectly opaque as any metal, and it is possessed of considerable lustre. It exists in nature native, but much more abundantly mineralized by sulphur, from which ore the quicksilver of commerce is usually obtained by distillation, lime or iron being added to retain the sulphur. In the state in which it is usually sold, it appears to be somewhat impure; at least it has been found, that by mixing it with an equal weight of iron-filings, and distilling from an iron retort, it is obtained more bright and mobile. The nature of the action of the iron in this experiment is not very obvious: it is found, however, to be essential, and it has been supposed to operate by the affinity it may exert to the small por-

tion of alloy, or of carbonaceous matter, which may be contained in common quicksilver.

Quicksilver, though liquid at any usual natural temperature, owes this form to the agency of caloric, and, by a sufficient reduction of temperature, can be obtained in the solid state. A prejudice had prevailed among the chemists, that the liquid state of mercury, and its mobility, were essential to it; but the falseness of this hypothesis, founded on very limited views, was demonstrated by its actual congelation. This appears to have been first observed in 1759, by Professor Braun of Petersburg, at that city; he being occupied in experiments on the power of freezing mixtures, and having found that the quicksilver in the thermometers which he employed was completely congealed, from their having been immersed in a mixture of diluted nitric acid and snow. The congelation of quicksilver had also been frequently produced by the operation of natural cold, particularly in Siberia; Gmelin and others having observed the mercury in the thermometer to sink so low in the tube, as we now know it could only have done in consequence of its congelation. Yet so general was the opinion of its natural fluidity, and at the same time so imperfect is this mode of making the experiment, that by no one, previous to Braun's experiments, except perhaps by De Lisle, was the just conclusion drawn, or the congelation of mercury believed *. From our knowledge of the modes of producing artificial cold, the experiment can now be easily performed in any country where snow or ice can be procured: and Mr Walker

* Philosophical Transactions, vol. lxxiii. p. 365.

has even shewn, that quicksilver may be congealed in a warm climate, without ice, by the successive action of mixtures of salts, previously cooled.

In passing to the solid state, quicksilver suffers a remarkable condensation, as great, as Mr Cavendish remarks from the experiments of Braun and Hutchins, as is equal to its expansion, from an augmentation of its temperature equal to 500° of Fahrenheit, which amounts to $\frac{1}{23}$ of its volume; and this gave rise at one time to a very erroneous estimate of its freezing point. In Braun's experiments, the mercurial thermometers he employed sunk to -244° , to -350° of Fahrenheit's scale, and, in subsequent experiments, even to -544° and -556° ; below which, of course, it was concluded that the freezing point of quicksilver must be placed. But this is a deception, from the great contraction of the quicksilver in the moment of its congealing, and even for some part of the scale of temperature previous to this; and by experiments since carefully made, so as to avoid this source of error, by Mr Hutchins at Hudson's Bay, the freezing point of mercury is fixed at -39° of Fahrenheit *.

In its liquid state, the specific gravity of quicksilver is, according to Brisson, 13.568: if we take the condensation which it suffers in becoming solid as equal to $\frac{1}{23}$, this gives its specific gravity, in the solid state, at its melting point, as equal to 14.176. Mr Biddle has determined this also by experiment: by weighing congealed mercury, under alkohol, with the hydrostatic balance at -40 , observing the loss of weight it sustained, and finding, by a

* Philosophical Transactions, vol. lxxiii. p. 321.

similar experiment, the loss of weight which an equal weight of silver, the specific gravity of which was known, sustained under the same circumstances, he inferred, that the specific gravity of mercury, in the solid state, at its melting point, is 15.612 *. The condensation in the congelation of quicksilver appears, from this experiment, to be much greater than in the calculation of Mr Cavendish. The difference in the density of solid quicksilver at its melting point, and of fluid quicksilver, at $+47$ of Fahrenheit's scale, is rather more than $\frac{1}{7}$ of the volume of the latter; and as the volume the fluid quicksilver occupies at -40 , must be somewhat less than at $+47$, the condensation in the act of congelation may be said to amount to $\frac{1}{7}$ of the volume of the fluid mercury, while, according to Mr Cavendish's estimate, it amounts only to $\frac{1}{25}$. This last, however, was inferred from rather imperfect data; on the other hand, Mr Biddle, on repeating the experiment, has found, that the specific gravity of solid mercury is not so great as he had informed. He states it at a little below the point of congelation, 14.465 †.

In congealing, quicksilver gives out a portion of caloric equal to what would raise its temperature while in the fluid form 152° of Fahrenheit ‡.

In its solid state, mercury possesses an evident degree of malleability, as it can be flattened with a hammer; at Hudson's Bay, it has been beaten on an anvil, to the thinness of paper. It is not possible to estimate its

* Nicholson's Journal, vol. x. p. 253.

† Philosophical Magazine, vol. xxx. p. 145.

‡ Journal de l'Ecole Polytech. tom. i. p. 123.

ductility. Its hardness, when thus near to its melting point, does not appear to be considerable.

In congealing, it assumes a crystalline structure and form. In its structure, it presents the appearance of striæ diverging from different centres; and when the liquid part is withdrawn from a quantity partially congealed, small octaedral crystals are discoverable*.

This metal is also easily volatilized: its boiling point being intermediate between 600° and 700° of Fahrenheit. The precise degree at which it boils, has been stated differently by different experimenters. Dr Irvine found, that with a mercurial thermometer, most accurately graduated, it boils at 672° †. Mr Crichton has stated it at 655° ‡; and Mr Dalton at 660° .

At the same temperature nearly as that at which it is volatilized, quicksilver is capable of combining with oxygen. When raised to this temperature, in contact with atmospheric air, its lustre diminishes, a film forms on its surface, and a quantity of a powder of a dull red colour accumulates: the oxygen of the air is absorbed, as Lavoisier proved, by performing the experiment in close vessels. The production of this red oxide, in any considerable quantity, is difficult, as the attraction of the metal to oxygen is not strong; and by the requisite heat, a part of the quicksilver is volatilized. The apparatus which answers best, is a glass-matrass with a wide bottom and long neck, the extremity of which is drawn nearly to a

* Annales de Chimie, tom. xxix. p. 248.

† Chemical Essays, p. 32.

‡ Philosophical Magazine, vol. xv. p. 147.

capillary point, as this admits of the renewal of the atmospheric air, and the circulation of the mercurial vapour, without allowing much of it to escape. The heat is applied by the medium of sand, and it requires its application for several days, before any sensible portion of the metal is oxidized.

This oxide is in the form of scales, of a red colour, with no great degree of lustre. If exposed to the heat of ignition in a glass-retort, it is decomposed, affording very pure oxygen, and returning to the state of quicksilver. From this experiment, Lavoisier inferred, that it contains seven parts of oxygen in 100 parts *. It is used in medicine as a very active mercurial.

Mercury, it has been believed, can likewise be oxidized at the common temperature of the atmosphere, by agitation or friction. It was known to the older chemists, that by agitation, either violent or long continued, a quantity of a black powder was formed from it; and that by separating this, and subjecting the remaining quicksilver again to agitation, a new production of the black powder takes place. Boerhaave formed a quantity of it by inclosing quicksilver in a strong bottle, which was fixed to the arm of a wind-mill. This has been regarded as a mere mechanical division of the metal, especially as it was found, that by exposing this powder to heat, it was reduced to running mercury. It has also been believed to be a real oxidizement. There is some degree of doubt with regard to this, Priestley having found, in some of his experiments, that the air in which the quicksilver is

* Mémoires de l'Acad. des Sciences, 1781, p. 464.

agitated is not sensibly injured; though he also states, what seems a contradiction, that the black powder, on being heated, becomes of an orange colour, dissolves like oxide of mercury in muriatic acid, and when heated strongly in a phial with common air, the air after the experiment was rather better, that is, contained more oxygen than before *.

This oxidizement, for it is probably such, can be more easily effected when the continuity of the mercury is divided by the interposition of any viscous matter, its surface thus increased, and the friction facilitated. Accordingly, by rubbing it with mucilage, oil, syrup, or honey, or even with dry powders, as chalk, the globules of mercury disappear; and, in this way, a number of mercurial preparations are formed, used in medicine, and much more active than metallic mercury.

Besides these, mercury exists in several other degrees of oxidizement in its combinations, though these degrees cannot be accurately determined. Thus, there are two well-known combinations of muriatic acid with oxidated mercury, in which the metal is in different degrees of oxidizement. These have been examined by Mr Chenevix, who has concluded, that the oxide in the one contains 10.7 of oxygen in 100 parts; that of the other 15 of oxygen in the same quantity *. The nitric acid, and perhaps also the sulphuric acid, is equally capable of combining with mercury in different degrees of oxidation.

* Experiments on Air, vol. iii. p. 467.

† Philosophical Transactions, 1802, p. 157.

The greater number of the acids act on mercury, are either capable of oxidizing and dissolving it, or of combining with its oxides ; and, as has just been remarked, these combinations take place with the metal in various degrees of oxidizement, capable of being influenced by a number of circumstances, and which, therefore, present results somewhat complicated. At the same time, these combinations have been more examined than perhaps those of any other metal, from their extensive medicinal applications, and are therefore well known.

Sulphuric acid has little effect on quicksilver, except when concentrated and aided by a high temperature. When boiled on it the acid is decomposed, the metal attracts a portion of its oxygen, and sulphurous acid gas is disengaged, while the oxide combines with another part of the acid. When boiled nearly to dryness, a saline mass is obtained, white and composed of minute prismatic crystals. This differs considerably in its properties, according to the proportions of the ingredients, and the degree of heat that has been applied. If two parts of acid have been used to one of metal, and if the process be stopt when the mercury disappears, and before the mixture becomes dry, the soft mass obtained tastes extremely sour and styptic, is very caustic, is deliquescent, and soluble in water. It is the perfect oxide of mercury combined with an excess of sulphuric acid, or a super-sulphate of mercury. If only $1\frac{1}{2}$ part of sulphuric acid be used, and if the process is stopt as soon as the mercury is converted into a saline mass, the metal is less perfectly oxidized, and at the same time contains less sulphuric acid. If it be washed with water, it carries off the ex-

cess of acid, with a portion of oxide in combination with this acid, and there remains a compound which no longer tastes sour, which is not acrid, is much less soluble in water, requiring not less than 500 parts of boiling water for its solution, is not decomposed by water, and which, by evaporation of its solution, affords prismatic crystals. This is the neutral sulphate, or salt resulting from the saturation of the imperfect oxide of mercury with sulphuric acid. It is likewise formed by diluting the acid with an equal quantity of water previous to its ebullition on the quicksilver, little sulphurous acid being then disengaged, and the metal being brought only to a low state of oxidizement. According to Fourcroy, who has examined with much attention the results of the action of sulphuric acid on mercury, it consists of 75 of mercury, 8 of oxygen, 12 of sulphuric acid, and 5 of water.

By continuing the application of heat, however, either to this compound, or to that which has been formed with the larger proportion of acid, more of the acid is decomposed, and the metal is completely oxidized, while the remaining sulphuric acid is unable to saturate this oxide. If a quantity of water is poured on this mass, it decomposes the sulphate of mercury; the greater part of the acid is abstracted, holding a portion of oxide in solution, and there remains the greater part of the oxide, with a portion of acid, however, still combined with it. The neutral sulphate is thus, by the affinity of the water, divided into a super-sulphate and sub-sulphate. The latter is in the form of a powder, of a lively colour, nearly insoluble in water: it is a preparation which was formerly known by the name of Turbith Mineral; which is now

named in the Pharmacopœia, Yellow Sub-Sulphate of Mercury. Although this can be obtained even from the neutral sulphate, yet, to prepare it economically, the application of the heat ought to be continued to the saline mass, obtained by the action of the sulphuric acid on the metal, until it is perfectly dry; as thus, there is less excess of acid, and on adding the water, less super-sulphate, and, of course, more sub-sulphate formed. The water ought also to be poured on the mass boiling hot; as at a high temperature, it abstracts more of the acid from the oxide, and thus forms a larger quantity of the sub-sulphate, as well as communicates to it a livelier yellow colour. According to Fourcroy, it consists of 76 of mercury, united with 11 of oxygen, 10 of sulphuric acid, and three of water; but the various shades of colour of which it may be obtained, prove that the proportions of its ingredients may vary. Another analysis has accordingly given the following proportions: oxide of mercury 84.7, sulphuric acid 15, water 3 *. This preparation being uncertain, and occasionally extremely violent in its operation, arising from the want of uniformity in its composition, has been nearly banished from medical practice.

Sulphate of mercury is decomposed by the fixed alkalis, and by lime, and a precipitate is thrown down, which was supposed to be an oxide, but which is probably a sub-sulphate, and which does not differ much in appearance from the sub-sulphate obtained by the preceding process, though it varies from a grey or a pale yellow to a red, from the state of oxidizement of the metal, or the

* Philosophical Magazine, vol. xxiii. p. 58.

quantity of acid that remains combined with it. Ammonia always causes a precipitate of a grey colour, as it not only separates the oxide, but decomposes it partially, from part of its hydrogen abstracting part of the oxygen. The precipitate, however, is not so abundant as that from the fixed alkalis, as the ammonia dissolves a part of it, forming a triple compound, which by evaporation of the liquor may be obtained in small crystals. According to Fourcroy, this ammoniaco-mercurial sulphate, as he names it, consists of 39 of mercury, 33 of ammonia, 18 of sulphuric acid, and 10 of water. There is reason to believe, that these saline combinations, whether neutral, or with an excess either of acid or base, may vary considerably, or almost indefinitely, in the degree of the oxidizement of the metal*. They are all decomposed by heat, which expels first the acid, and afterwards the oxygen of the oxide.

Nitric or nitrous acid acts rapidly on mercury in the cold. Nitric oxide gas and nitrous acid vapour are disengaged, the metal is oxidized, and combines with a portion of the acid. The nature of this action is different, according to the circumstances under which it takes place, and the knowledge of it is important from its relation to pharmacy.

If the nitric acid is diluted with at least an equal part of water, and if no heat is applied to accelerate its action on the mercury, comparatively little nitric oxide gas is disengaged; the metal is combined with the smallest quantity of oxygen; and this imperfect oxide, as it may

* Chemical Statics, vol. ii. p. 468.

be termed, is combined with the nitric acid. In this case the acid can dissolve nearly twice its weight of mercury.

If, again, the acid is in larger proportion, less diluted, and especially if its action is promoted by heat, it is rapidly decomposed: a large quantity of nitric oxide gas is expelled: less of the metal is dissolved, but it is saturated with oxygen; and this perfect oxide combines with the remaining acid. These two compounds are both termed Nitrate of Mercury, in the new nomenclature, but it is evident that they differ in their composition,—the one containing the metal in its lowest state of oxidizement, the other containing it saturated with oxygen. Both, when the solution is completed, crystallize; the crystals being a congeries of slender prisms, or octaedrons if formed more slowly. These are deliquescent; they are soluble in water; or, if the solution be merely heated, they are again dissolved. The solution is corrosive. The difference between these two compounds is therefore not very great with regard to properties, but it is easily discovered by their relations to other chemical agents, particularly by the very different precipitates they afford when decomposed by the alkalis.

It is to be remarked, however, that the mercury is not easily obtained in the highest state of oxidizement, by causing even the concentrated acid to act on the metal. It is obtained with more certainty by dissolving the perfect oxide of mercury in nitric acid. A compound of this kind is thus obtained which may be crystallized. There is every reason to believe, that the metal does not combine with the acid merely in two or three determinate degrees of oxidizement, but in all degrees between the

maximum and *minimum*; these degrees being determined by the circumstances of the reciprocal action.

It is also obvious, that any of these solutions may be formed with an excess of acid, from the proportion employed relative to that of the metal. This excess renders the saline combination still more soluble, more permanent, and susceptible of dilution with water without decomposition, and likewise more acrid and corrosive: it is the common state of solutions prepared in the cold.

On the other hand, a nitrate of mercury may be formed with an excess of oxide. This is obtained, either when nitric acid, diluted with an equal weight of water, is boiled on quicksilver, until it can dissolve no larger portion of the metal, or by adding to a solution of nitrate of mercury, prepared in the cold, a quantity of metallic mercury, and boiling them together. In the first case, the heat so far aids the affinity of the metal to oxygen, that it decomposes so much of the acid as to form this compound with excess of oxide; in the second case, the quantity of metallic mercury added, attracts a portion of the oxygen of the oxide already in solution, and also of the acid, (though not much of this is decomposed, as there is scarcely any disengagement of nitric oxide); and there being only as much acid present as saturated that oxide, it is obvious, that the compound must now have an excess of oxide. This compound, though it has an excess of oxide, remains soluble, and as it cools, crystallizes; but if water is added to it, it is decomposed; it becomes turbid, and a subnitrate of mercury, sparingly soluble, is precipitated, while a portion of the combination, approaching more nearly to the state of the neu-

tral nitrate, remains in solution. This nitrate of mercury, with excess of oxide, appears from the mode of its formation, always to contain the metal in a state of oxidizement, intermediate between that of the two neutral nitrates above described, not so highly oxidized as the one, and more so than the other, and perhaps indefinite as to its degree between these two: and, accordingly, what is a proof of this, when muriatic acid is added, portions of the two well-determined compounds which result from the union of that acid, with mercury in two states of oxidizement, are formed; the muriatic acid, by its affinity, resolving the medium oxide, as it may be named, of the nitrate, into these two oxides with which it unites. It appears difficult to form a nitrate of mercury with excess of oxide, in which the metal is either at the *maximum* or *minimum* of oxidizement.

If any of the nitrous solutions or salts of mercury be exposed to heat until it is reduced to a perfectly dry mass, the metal always passes to a high state of oxidizement, by the temperature facilitating the decomposition of the acid; and, at the same time, more or less of the acid is disengaged, as the temperature is raised. The mass thus acquires at first a yellow colour; and if the application of the heat be continued, it assumes a brilliant red colour and scaly appearance. This is a preparation which has long been used in medicine as an escharotic, under the name of Red Precipitate of Mercury. The process usually given to prepare it, is to dissolve quicksilver in rather more than its own weight of diluted nitric acid, with the assistance of heat: continuing the application of the heat, until the solution is reduced, by evaporation, to a

dry mass, which, being reduced to powder, is urged with a strong fire, until it assume the brilliant red colour.

It has always been found difficult to obtain this compound, when the process is performed on a small scale, of that bright red colour which is regarded as a proof of its proper preparation and purity. Many directions have been given for attaining this, but the greater number are useless or prejudicial. Much appears to depend on the quantity in which it is prepared. According to M. Payssé, who had examined the process as carried on in some of the chemical manufactories in Holland on a large scale, and who has given a memoir on this subject *, it depends principally on the heat being equally and steadily applied, without being raised too strong, by which the bright red colour is destroyed; and he has given the following process for its preparation. "Take mercury, free from every other metallic matter, 50 parts; nitric acid, deprived as much as possible of muriatic acid, and of from 34 to 38 degrees, 70 parts; dissolve the metal in the acid, and assist their reciprocal action by a gentle heat in a sand-bath; evaporate by distillation, and take the receiver from the retort when the vapours of the nitrous gas begin to manifest themselves, as they announce the decomposition of the mercurial nitrate. The point here is to employ a constant and moderate temperature, if you wish to insure success to the operation: it is raised a little towards the end, that is to say, when the disengagement of the gaseous nitrous acid is no longer manifested, but in a

* *Annales de Chimie*, tom. li. p. 202. or *Philosophical Magazine*, vol. xxii. p. 126.

manner not very sensible : the vessel must be exposed to this degree of heat till it is observed that the mass of red mercurial oxide is of a bright and brilliant red colour in all its parts. Eight hours of heat are in general sufficient for 400 pounds of this substance *."

This preparation has been regarded as an oxide of mercury, the whole of the acid being supposed to be expelled from it by the heat. This, however, does not appear very probable. While the mercury remains in the state of oxide, it will probably always retain a portion of the acid by its affinity to it, which in this case is so much aided by the relative quantity : the preparation, too, is very different in its external appearance from the red oxide of mercury, prepared by exposing mercury to the action of atmospheric air at a high temperature ; and it is always much more acrid and corrosive,—qualities which it probably derives from the acid it contains. When decomposed by heat, this acid will be resolved into its elements, and will therefore not be apparent, nor will the nitrogen be easily discovered, diluted as it must be with the oxygen both of the acid and the oxide. Indeed, the analysis has not been performed with accuracy with the view of discovering it. The proper name of the preparation is Red Sub-Nitrate of Mercury. M. Payssé has stated, that when decomposed by heat, 100 parts afford 82 of mercury, and 18 of oxygen, while the preparation, which is of a dull red colour, does not give more than 13 or 14 of oxygen in this decomposition.

Nitrate of mercury is decomposed by the alkalis, and

* Philosophical Magazine, vol. xxii. p. 130.

by several of the earths; but the phenomena of these decompositions are different, according to the state of oxidizement of the metal. If potassa, soda, or lime, is added to the solution of mercury, made in the cold and with the diluted acid, in which it is little oxidized, a greyish precipitate, with a tinge of yellow, is produced: when added to the solution in which the metal is more highly oxidized, the precipitate is yellow, with a mixture of white. In both these cases, the alkali combines with the acid, and separates the oxide. The difference, therefore, in the precipitate, shews the different states of oxidation in which the metal exists in these solutions. The oxide, however, in separating, still retains a portion of the acid in combination, as Bayen proved.

Ammonia exerts a more peculiar action on the nitrates of mercury, which requires to be particularly noticed.

If the solution of mercury be that which contains the metal in the least oxidized state, the precipitate is of a dark blue colour, approaching to black: it is the metal in the lowest state of oxidizement; and as it is mild in its operation, it is frequently used in the practice of medicine. It is inserted in the Pharmacopœia under the name of *Oxidum Hydrargyri Cinereum*, or ash-coloured oxide of mercury. To prepare it, four parts of quicksilver are dissolved in five parts of diluted nitrous acid; that is, of acid diluted with an equal weight of water: the solution is diluted with 15 parts of distilled water, and water of carbonate of ammonia is added as long as any precipitation is produced: the black precipitate is then washed with water, and dried.

In this process, it was supposed that the ammonia mere-

ly combined with the nitric acid, and that the oxide of mercury was precipitated. The precipitate, however, is different from that produced by adding to the same solution the fixed alkalis or lime, either of which likewise merely attracts the acid, and separates the oxide; hence it is evident, that the ammonia re-acts on the oxide which it separates, and produces in it some change. Fourcroy shewed the nature of this change. When the ammonia is added to the nitrate of mercury, it combines with the nitric acid, and separates the mercurial oxide; but this oxide, in the moment of its separation, is partially decomposed: part of its oxygen is attracted by part of the hydrogen of the ammonia: a small quantity of nitrogen gas is of course disengaged, and the metal is precipitated in its lowest state of oxidizement,—one considerably lower than that in which it existed in the nitrate of mercury.

The action of ammonia now described, is that which it exerts upon the solution of mercury in nitric acid, made with a diluted acid, and in the cold, and in which the metal is only imperfectly oxidized. Its action is considerably different upon the other solution, in which, from the use of a concentrated acid, or the application of heat, the mercury is more highly oxidized. The precipitate thrown down is white. Fourcroy has likewise examined the nature of this precipitate. He found, that it is not a pure oxide, but a ternary combination of oxide of mercury, ammonia, and nitric acid. When the ammonia is added to the solution, it combines with part of the nitric acid, and separates the oxide, which, in the moment of its separation, attracts a portion of ammonia and of nitric acid, and forms the triple compound, which constitutes the

white precipitate that is thrown down. This precipitate is decomposed by heat, and affords ammonia, nitrogen gas, oxygen, and mercury. According to Fourcroy, it consists of 68.2 of oxide of mercury, 16 of ammonia, and 15.8 of nitric acid and water *. It is capable of combining with an excess of ammonia, and is thus rendered more soluble in water.

The knowledge of the different states of oxidizement in which mercury may exist in combination with nitric acid, and of the different actions of ammonia on these oxides, enables us to determine the circumstances necessary to be attended to in the preparation of the grey precipitate of mercury, which, from these circumstances not being attended to, is met with very variable in its qualities, being sometimes of a dark colour, sometimes of a light blue, and of all the shades intermediate between these. These differences arise from the manner in which the solution of mercury has been prepared. If the acid has not been much diluted, or if the temperature has been high, the mercury will be highly oxidized. In this case, on first adding ammonia, a dark-coloured precipitate is thrown down, but, on continuing the addition, a white precipitate is formed, which, mixing with the other, renders its colour lighter: If heat has been applied to the solution to accelerate it, the metal is so highly oxidized, that the precipitate afforded is of a very light blue colour. These differences must occasion a difference in the action of this preparation as a remedy, since as the one precipitate differs entirely from the other in compo-

* Annales de Chimie, tom. iv.

sition, their action on the system must likewise differ. The object to be attended to, to obtain the dark-coloured precipitate pure, is evidently to diminish the action of the acid on the metal, as much as is compatible with the solution going on, as we are then certain that the mercury will be less perfectly oxidized. A process of this kind has been described by Hahneman, which answers exceedingly well. The acid is diluted with two parts of water, only one-fourth or one-sixth of its weight of mercury is added to it at first, and the vessel is placed in cold water, to prevent any rise of temperature from the solution. The decomposition of the acid goes on in this manner very slowly, and without any sensible effervescence. When the mercury is dissolved, another portion is added; and this is repeated till the acid has taken up its own weight of metal, or, in general, till it is saturated. We thus obtain a solution, in which all the mercury is in the lowest state of oxidizement: it is diluted with twenty parts of distilled water, and ammonia is added as long as any precipitate is produced. This precipitate, which is of a very dark colour, is immediately washed with water, and dried on bibulous paper placed before the fire. Its colour becomes lighter, while drying, from the action of the light and air; but it is still of a dark grey, and, when prepared in this manner, is always uniform in its composition.

Mercury is not acted on by the muriatic acid, as it is unable to decompose the water contained in the acid, and cannot therefore be oxidized. But it is dissolved by the oxymuriatic acid, the excess of oxygen passing to the metal, and the oxide of mercury combining with the acid, thus reduced to the state of common muriatic acid. If any

of the oxides of mercury be added to muriatic acid, a combination likewise takes place; or if the acid, or any of its salts, be added to the nitrate of mercury, it immediately attracts the oxide, and forms muriate of mercury.

The compounds which the muriatic acid forms in any of these cases, are different, according to the degree of oxidizement of the mercury. With the imperfect oxide it forms a compound insipid and inert, and likewise insoluble in water; with the perfect oxide, one which is on the contrary abundantly soluble, and highly acrid.

When muriatic acid is added to the solution of mercury made in the cold, and with the diluted acid, the compound formed is, of course, principally that of the former kind,—the insipid and insoluble muriate of the metal. But as it is scarcely possible to obtain a solution of mercury in nitrous acid, in which the metal is not in rather a higher state of oxidizement, so there is generally formed at the same time a quantity of the other compound, that of the perfect oxide with muriatic acid, which is soluble and acrid. The presence of this is easily discovered, by pouring off the clear liquor from the insoluble muriate, and adding to it a small quantity of ammonia. If there is any of the acrid or soluble muriate of mercury present, a white precipitate is immediately formed, which is a ternary compound of oxide of mercury, ammonia, and muriatic acid. When the solution of mercury in the nitric acid has been prepared by the action of a strong acid, aided by heat, more of the corrosive muriate of mercury is formed, and proportionally less of the other, though there is always a proportion of the latter.

It might be imagined, that in these cases the metal had

existed in the two states of oxidizement in the nitrous solution, one portion of it in the one, the other in the other, and that with these two oxides the muriatic acid merely combines. But it is more probable, that the metal in the solution is always in one state of oxidizement intermediate between the *maximum* and *minimum*, and that the muriatic acid, by its affinity to the oxide in one or other of these states, causes a change in the state of oxidizement; or, instead of immediately combining with the oxide united with the nitric acid, whence only one combination would result, resolves it into the two oxides, from its union with which, the corrosive and mild muriates of mercury are formed; the proportions of these being, of course, various, according to the state of the solution, that of the corrosive muriate being always greater, as the metal is more highly oxidized. Accordingly, if a solution is prepared by adding the perfect oxide of mercury to nitric acid, on adding to this solution muriatic acid, corrosive muriate of mercury is alone formed.

These two compounds of the oxides of quicksilver are very different in their qualities. That with the perfect oxide is acrid, corrosive, and soluble in water; that with the imperfect oxide is mild, insipid, and insoluble. They have both been long used in the practice of medicine, the one under the name of Corrosive Sublimate of Mercury, the other under that of Sweet Sublimate, or Calomel. The former is now named in the Pharmacopœia, Muriate of Quicksilver, the other Sub-muriate of Quicksilver;—names, which, as is immediately to be remarked, do not properly denote their composition, and which scarcely distinguish them sufficiently.

Though these two compounds can be formed in the manner now described, the usual methods of preparing them are different, and are preferable, as being more economical, and as affording more uniform products.

To prepare the corrosive muriate of mercury, the old process is to dissolve 16 parts of quicksilver, in an equal weight of diluted nitric acid, with the assistance of heat : the solution is then evaporated to dryness. The dry mass reduced to powder, is mixed with 20 parts of dried muriate of soda, and 20 parts of dried sulphate of iron. This mixture is put into a matrass or flask, covered with a coating of clay and sand, and is sublimed by the heat of a sand-bath. The sublimed matter is the corrosive muriate of mercury.

In this process, the metal is first oxidized by the agency of the nitric acid ; and in the sub-nitrate obtained by evaporation, the mercury exists in the highest state of oxidizement. When mixed with the muriate of soda and sulphate of iron, and exposed to heat, the sulphuric acid of the sulphate of iron combines with the soda of the muriate of soda : the muriatic acid is disengaged, and is attracted by the oxide of mercury, with which it forms the corrosive muriate. This being volatile, is sublimed by the heat ; but being also easily condensed, it adheres to the upper part of the subliming vessel. The matter which remains in the bottom of the vessel is the sulphate of soda, mixed with the oxide of iron. The quantity of nitric acid that was combined with the oxide of mercury is expelled by the heat during the process.

A different mode of obtaining this preparation has been introduced into the Pharmacopœia, supposed to be

more economical, as the expence of the nitric acid is avoided. One part of quicksilver is boiled with two parts of concentrated sulphuric acid. The metal is oxidized by the sulphuric acid, and then combines with a portion of it : the solution is evaporated to dryness. This dry sulphate of mercury is mixed with four parts of muriate of soda ; and the mixture is exposed in a subliming vessel to a sand heat. A double decomposition takes place ; the sulphuric acid combines with the soda of the muriate of soda, and the muriatic acid of this salt combines with the oxide of mercury. The muriate of mercury which is thus formed is sublimed, and the sulphate of soda remains at the bottom of the vessel. It may be doubted whether this process affords so uniform a result as the other, or rather if it gives so large a product from a given quantity of mercury ; the deficiency being owing probably to the sulphate of mercury not containing so much sulphuric acid as is necessary to decompose a sufficient quantity of muriate of soda, to afford the requisite proportion of muriatic acid, to combine with all the oxide of mercury which is present.

Corrosive muriate of mercury, as prepared by the process of sublimation, is in the form of a white compact mass, semi-transparent, and having somewhat of a crystalline arrangement ; and when the sublimation has been performed slowly, it is condensed in the neck of the matrass in the form even of regular crystals, which are long slender tetraedral prisms. It crystallizes also, from its saturated solution in water in prisms, and likewise, as has been affirmed, in cubes. That it is volatile by heat is evident, from the process of obtaining it by sublimation ;

and it is volatilized without being decomposed. It is soluble in water, requiring about 20 parts at the temperature of 60° for its solution, and not more than two parts of boiling water. It is also soluble in alkohol, which is capable of dissolving a much larger quantity of it than water does. It changes to a green, some of the vegetable colours. The taste of this salt is styptic, and extremely disagreeable; and it acts as a poison, a very small quantity of it inducing inflammation of the stomach, so that it cannot be properly administered in larger doses than the eighth or sixth part of a grain at a time. In such doses, however, and administered with caution, it has long been in use as the most active of the mercurial preparations.

This salt is not decomposed by the acids, which do not appear to exert to its oxide a stronger attraction than the muriatic acid does. It is therefore dissolved by them without suffering any apparent change; though, in such solutions, a ternary combination of the two acids with the oxide of mercury is no doubt formed. It is decomposed by the alkalis. Potassa, soda, and several of the earths, throw down a precipitate of a yellow or orange colour, which is a sub-muriate of mercury. Ammonia gives a precipitate perfectly white. This has been in use as a mild escharotic, under the name of White Precipitate of Mercury. It has been examined by Fourcroy, who has shewn that it is a triple combination of oxide of mercury, muriatic acid, and ammonia; the proportions being 81 of the first, 16 of the second, and 3 of the last. When formed, the ammonia which is added, attracts part of the muriatic acid of the corrosive muriate of mer-

cury, the oxide is precipitated, retaining a portion of the acid, and attracting at the same time a small quantity of the ammonia. When exposed to heat, it is decomposed; ammonia and nitrogen gas being disengaged, and a grey sublimate being obtained, which appears to be imperfect oxide of mercury in combination with muriatic acid, with perhaps a portion of metallic mercury diffused through it, and giving it this colour.

Muriate of ammonia exerts an action on corrosive muriate of mercury somewhat singular, and which has, accordingly, attracted the notice of chemists. It renders the muriate of mercury much more soluble in water, one part of it rendering nearly five parts of the other soluble in three parts of water. The two salts remain in combination, when obtained solid either by crystallization or sublimation, and form a ternary compound of muriatic acid, ammonia, and oxide of mercury. To this combination, the alchemists gave the barbarous name of *Sal Alembroth*. When potassa or soda is added to its solution, it attracts the greater part of the muriatic acid, and the oxide of mercury is precipitated, combined with a portion of acid and of ammonia, forming the very same preparation as that which is obtained by adding ammonia to the solution of the muriate alone; and, indeed, that preparation was generally obtained by this indirect process, of dissolving corrosive muriate of mercury with an equal weight of muriate of ammonia in water, and adding a solution of potassa, to throw down the precipitate.

Corrosive muriate of mercury is decomposed by sulphuretted hydrogen, by the hydro-sulphurets, and sulphuretted hydro-sulphurets added to its solution: a precipitate

is thrown down of a black colour, which appears to be sulphuretted oxide of quicksilver.

It suffers decomposition from a number of the metals which attract oxygen from the mercury. Iron or copper immersed in its solution, abstract the oxygen of the acid partially, and a precipitate is formed, which is the mild muriate, or the mercury in a low degree of oxidizement, combined with muriatic acid. When heat is applied to favour the action of the metals on the corrosive muriate, the decomposition is more complete : both the oxygen and the acid are transferred to the metal employed, and the quicksilver returns to the metallic state. Thus, if two parts of the muriate of mercury be mixed with one part of antimony, of arsenic, or of bismuth, reduced to powder or to filings, and exposed to heat in a retort, vapours pass into the receiver, which condense into a thick liquid or jelly : this consists of the metal added, in combination with the oxygen and muriatic acid of the muriate of mercury ; and by continuing the distillation, metallic mercury passes over, or, if the metal employed is one to which quicksilver has an affinity, it retains a portion of it, forming an amalgam. These decompositions take place also with the sulphurets of these metals ; and in this case, the mercury remains combined with the sulphur in the state of a sulphuret, or a sulphuretted oxide.

The corrosive muriate of mercury being a salt important from its medicinal use, the precise composition of it has often been attempted to be determined. Without taking notice of those analyses, which the state of chemistry formerly rendered necessarily imperfect, it is suffi-

cient to give the result of the researches of Mr Chenevix on this subject.

From the relation subsisting between the corrosive and the mild muriate of mercury, and in particular from the mode of preparing the latter from the former; it was evident, that the corrosive muriate contained a larger quantity of oxygen in its composition. Some chemists had conceived, that this larger proportion of oxygen is combined with the acid, and that, of course, it is in the state of oxymuriatic acid, which, in the corrosive muriate, is combined with an oxide, similar to that in the mild muriate. Though this opinion rested on no foundation, it was examined by Mr Chenevix, and proved to be incorrect: the acid in the corrosive muriate is the muriatic acid; and the larger portion of oxygen which it contains, compared with the mild muriate, is combined with the metal, which is therefore in a high state of oxidizement. By Mr Chenevix's experiments it is proved, that the oxide which exists in corrosive muriate, consists of 85 of mercury, with 15 of oxygen; and that in this muriate 82 parts of this oxide are combined with 18 of acid. 100 parts of it therefore consist of 69.7 of mercury, combined with 12.3 of oxygen, forming 82 of oxide, with which 18 of muriatic acid are combined*.

The other compound of muriatic acid and mercury, in which the metal is in a lower state of oxidizement, the Mild Muriate, as it may be named, has been long prepared from the corrosive muriate, by bringing a quantity of metallic mercury into combination with its principles, by

* Philosophical Transactions, 1802, p. 156.

which of course the whole metal is less highly oxidized. For this purpose, the corrosive muriate of mercury is triturated in a glass or stone mortar with nearly an equal weight of pure mercury, the trituration being continued till the mercurial globules are no longer perceptible: a grey powder is thus formed, which is introduced into a glass-matrass, and exposed to a moderately strong heat, applied by the medium of sand. It sublimes, and forms a crust on the upper part of the vessel: this is reduced to powder, and again sublimed; and this sublimation is repeated for a second or third time. The use of these repeated sublimations is to render the combination more perfect, as, at the first sublimation, a portion both of corrosive muriate and of metallic mercury sublime unchanged. But by trituration, and a second application of heat, this mercury is brought into combination, and the whole resolved into mild muriate. There is perhaps no necessity for more than two sublimations; and when reduced to a fine powder by levigation, in which state it is always used, it ought to be washed with water, until the water pass off tasteless, by which any corrosive muriate, if present, will be removed.

The theory of this process is sufficiently evident. The quicksilver, which is added to the corrosive muriate, and by the trituration and application of heat is enabled to exert its affinities, must deprive the oxide, which is the base of that salt, of a portion of its oxygen, and the whole be brought to a lower state of oxidizement. It is equally obvious, that this oxide remaining in combination with the acid of the corrosive muriate, the mild muriate which is formed, must have a less proportion of acid combined

with its base than the other, though it has still a quantity sufficient to produce saturation : and these two salts thus afford an excellent illustration of the general principle which holds with regard to many metallic combinations, that a metal, when in a high state of oxidizement, requires more acid for its saturation than when its oxidizement is lower ; the quantity of acid in the corrosive muriate being sufficient to saturate the larger quantity of oxide that is formed, by the addition of metallic mercury, in the process for converting it into the mild muriate, merely from that oxide being in a state of oxidizement lower than that which exists in the corrosive muriate of mercury.

From the nature of the process by which mild muriate of mercury was formed, it was thus evident, that it differs from the corrosive muriate, in containing less oxygen and less acid proportioned to the quantity of metal, or, in other words, that the metal is at a lower degree of oxidizement, and this oxide is combined with a smaller quantity of acid. This view has been confirmed by the experiments of Mr Chenevix. He has found, that the oxide which forms the base of the mild muriate, is composed of 89.3 of mercury, and 10.7 of oxygen, and that in this salt 88.5 of it are combined with 11.5 of muriatic acid. Hence 100 parts of it consist of 79 of mercury, combined with 9.5 of oxygen, forming 88.5 of oxide, with which 11.5 of muriatic acid are combined.

It is difficult by any nomenclature to express clearly the distinction between these two muriates of mercury. The one has been named Muriate, the other Sub-muriate, but these terms cannot be regarded as correct. The epithet *sub* is prefixed, according to the principles of the modern

chemical language, to a salt in which there is a deficiency of acid, or less than is requisite to saturate the base. But in the mild muriate this is not the case : the oxide is combined with as much acid as it requires ; and it contains less than the corrosive muriate does, only because less acid is requisite for the saturation of the imperfect than of the perfect oxide. Nor is the name of muriate of mercury applied with more propriety to the one of these compounds than to the other. Indeed, by those chemists who denote the metallic salts which contain the metal in a high state of oxidizement, by prefixing the syllable *oxy*, the name muriate of mercury will be given to that which others have named sub-muriate ; and thus the same name will, on different authorities, be applied to two salts extremely different, and which it is highly dangerous to confound. From both being extensively used in medicine, and from the one being a poison, while the other is comparatively inert, it is of the first importance to give them very appropriate names ; and perhaps no better can be devised than prefixing the epithets *corrosive* and *mild*, which have long been applied to them, and which at once point out the quality with regard to which it is of most importance to distinguish them. Even in a chemical point of view, this nomenclature is correct ; for, as has been already observed, the distinctions between the salts of the different oxides of the same metal, united with the same acid, are best drawn from some striking property in which they differ ; and though the distinction is generally taken from colour, yet, where the colour is the same, or where there is any particular propriety in deriving it from any other property, (both which reasons exist in the

present case), this may be done in conformity to the principles of the nomenclature.

Another mode of preparing mild muriate of mercury has been introduced, proposed by Scheele. It consists in dissolving quicksilver in an equal weight of diluted nitric acid, promoting the solution by the application of heat : muriate of soda, in quantity equal to rather more than half the weight of the quicksilver dissolved, is dissolved in boiling water, and into this, while warm, the solution of muriate of mercury is poured. A precipitation takes place : from the precipitate, after it has subsided, the clear liquor is poured off, and it is washed with water until the water pass off tasteless. In the process, it is obvious, that the mercury is first oxidized by the nitric acid, and is then dissolved by the remaining acid. On adding to this the solution of muriate of soda, the soda combines with the nitric acid of the mercurial solution, while the muriatic acid unites with the oxide of mercury. The same product is obtained by adding muriatic acid alone to the nitrous solution ; but it is better to use muriate of soda, the soda of which saturates the nitric acid, which otherwise, when disengaged uncombined, acts on the mercurial oxide, and communicates to it a portion of oxygen.

From the nature of this preparation, it is obvious, that the mercury in the nitrous solution ought to be in the lowest state of oxidizement, as it is only in this state that it forms the mild muriate ; and if more highly oxidized, a portion of corrosive muriate will be formed. When Scheele, however, proposed the process, the theory of metallic solutions was imperfectly understood ; and on the supposition, that by boiling the acid on the metal, it would

be more completely saturated with it, he directed the application of heat. From this, one source of error is introduced into the process: there is such an excess of oxide in the solution, that the mere affusion of water precipitates a portion of insoluble sub-nitrate; and hence, when, according to the above directions, the solution of mercury is poured into the solution of muriate of soda, the water of the solution throws down a quantity of this sub-nitrate, mixed with the precipitate of the portion of muriate that is formed. Another source of error is, that by the application of heat, the metal is more highly oxidized, and hence the solution gives less mild muriate, and more corrosive muriate, than the solution does that is formed in the cold. This has been doubted by some chemists, from it being observed, that the additional portion of mercury which the heat causes to be dissolved, is taken up without any sensible effervescence; and hence it has been inferred, that none of the acid is decomposed, so as to oxidize the metal more highly. Mr Chenevix has admitted this opinion in his researches on this subject. The metal must, however, pass to a high state of oxidizement at the first application of the heat, and some portion of the acid must continue to be decomposed to the end of the solution; for the fact is, that more corrosive muriate of mercury is formed, when the solution of mercury has been prepared with heat, than when the one prepared in the cold is employed, as I have often found on experiment. And if the process of Hahneman, for preparing the solution of nitrate of mercury in the cold, already delivered, be followed, scarcely any corrosive muriate is produced, but the whole is converted into mild muriate. With at-

tention to this circumstance, this process may be employed for the formation of this preparation, but it has no advantage over that by sublimation, and, as liable to furnish a less uniform product, it ought perhaps to be discarded. Prepared according to the common process, it is always a mixture of mild muriate, and of sub-nitrate of mercury; and if not very carefully washed, a portion even of corrosive muriate will be mixed with it.

Mild muriate of mercury prepared by sublimation, is in the form of a dense mass, of a much greater specific gravity than the corrosive muriate, that of the one being 5.1398, of the other 7.1758: it has a yellowish tinge, while the corrosive muriate is quite white. It displays a crystalline structure; the mass being composed of an aggregate of short prisms, and, when sublimed slowly, it condenses in tetraedral prisms acuminated by four planes, or in octaedrons, composed of two quadrangular pyramids united by the base. When in its dense state, it has a slight degree of ductility, and is semi-transparent. It is volatile, but rather less so than the corrosive muriate. It is so little soluble, as to require, according to the experiments of Rouelle, 1152 parts of water for its solution. It is perfectly mild and insipid, and as a medicine has much less activity than the corrosive muriate, though better adapted by its operation to many medicinal purposes, and therefore more extensively employed.

This salt is changed or decomposed by a number of chemical agents. It is soluble in muriatic acid: oxymuriatic and nitro-muriatic acids, by affording oxygen to its oxide, convert it into corrosive muriate. The alkalis decompose it by abstracting the greater part of its acid.

Potassa, soda, or lime in a state of solution, triturated with it in powder, give it a greyish colour by this operation. Ammonia renders it almost perfectly black; the ammonia, while it separates the oxide of mercury, still farther de-oxidizing it. This black matter is very similar to the grey oxide thrown down by ammonia from that solution of mercury in nitric acid in which the metal is in a low state of oxidizement.

It does not appear that muriatic acid combines with mercury in any state of oxidizement intermediate between those oxides which afford the mild and the corrosive muriates. When added to any mercurial salt, in which the metal is in such an intermediate state, the acid does not combine with the oxide, but resolves it into these two oxides, with which it then combines. Or if a portion of metallic quicksilver is added to the corrosive muriate inferior to that which is requisite to change the whole of it into mild muriate, there is no intermediate compound; but, with a portion of mild muriate, a quantity of corrosive muriate is sublimed.

The experiments of Mr Chenevix have proved, that an oxymuriate, or, as he considers it, a hyper-oxymuriate of mercury, or combination of the perfect oxide with hyper-oxymuriatic acid, may be formed. He transmitted a current of oxymuriatic acid gas through water, in which red oxide of mercury was suspended. After a short time, the oxide became of a very dark brown colour, and a solution took place. On evaporating the liquor to dryness, a great proportion of corrosive muriate was found in the mass; but by carefully separating the last-formed crystals, some hyper-oxygenized muriate of mercury was obtained: on

crystallizing it a second time, it was obtained nearly pure. This salt is more soluble than corrosive muriate; about four parts of water retaining it in solution. Acids poured on it disengaged the usual smell of hyper-oxymuriatic acid, and the liquor became of an orange colour *.

Mercury is not acted on by any of the other acids, but its oxides form combinations with them. These combinations may be formed, either by digesting the acid on the oxide, or by adding to a solution of nitrate of mercury a solution of a salt containing the acid with which the oxide of mercury is to be combined; when a complex affinity produces a mutual decomposition, and two new combinations. Thus, if a solution of phosphate of soda be added to a solution of nitrate of mercury, the soda combines with the nitric acid, and a precipitate of phosphate of mercury is formed: and similar decompositions are effected by the greater number of the other neutral salts. The combinations thus obtained, must vary according to the state of oxidizement of the mercury in its nitrous solution: but it is principally those salts formed with the imperfect oxide that have been taken notice of, as it is the solution in which this oxide exists, that generally affords precipitates with the acids.

Of the remaining salts which can be introduced in this place, the phosphate, the preparation of which has just been described, is in the form of a white precipitate, insoluble in water, mild and insipid. It is said to be phosphorescent, and, when exposed to a high temperature, is decomposed, affording phosphorus. The fluuate of mer-

* Philosophical Transactions, 1802, p. 160.

cury is in the form of a white precipitate, insoluble. The borate is of a yellowish colour. Neither have been particularly examined. The carbonate of mercury formed by the addition of carbonate of potassa or soda to the solution of nitrate of mercury, is of a white colour, with a shade of yellow; and its formation is very well demonstrated by this colour of this precipitate, as that by pure potassa or soda, from the same solution, is of a deeper colour. It preserves its colour on exposure to the air, while the other deepens, though still, in drying, it acquires a brown tinge. It is applied to no use.

The oxides of mercury precipitated from their combinations with the acids, by the alkalis or earths, especially by ammonia or lime, Bayen discovered, are capable of having a detonating quality communicated to them, by combination with sulphur. If triturated with one-sixth of their weight of sulphur, on being exposed gradually to heat, they explode with considerable force. It is an essential circumstance in the preparation of these precipitates for this purpose, that they be dried in the open air, and exposed to the light*.

Another fulminating preparation of mercury, of greater power, has been discovered by Mr Howard. His discovery of it was accidental. In making some experiments, in which the red oxide of mercury had been mixed with alcohol, and afterwards some nitric acid added, a precipitate was formed, to which, after it was dried, sulphuric acid was added, and immediately a violent explosion unexpectedly took place. The process which Mr

* Opuscles Chimiques, tom. i. p. 346.

Howard, after a variety of experiments, found to succeed best in preparing this fulminating mercury, was to dissolve 100 grains of mercury in one ounce and a half of nitric acid by measure : the solution, when cold, is *poured upon* two ounces by measure of alkohol : a moderate heat is to be applied till an effervescence is excited, when a precipitate is formed : it is to be immediately collected on a filtre, well washed with distilled water, and carefully dried in a heat not much exceeding that of a water-bath. From 100 grains of mercury, about 120 or 130 grains of dry precipitate are formed. According to Brugnatelli, it may also be prepared without heat, merely by pouring on the yellow sub-sulphate of mercury, about four times its weight of alkohol, and five times its weight of nitrous acid, an effervescence taking place, and the concrete matter being fulminating mercury *.

This preparation fulminates strongly. If two grains of it be laid upon an anvil, and struck smartly with a hammer, it explodes with a very loud report. Three or four grains occasion indentations both in the hammer and anvil. The shock of an electrical battery has the same effect, as has also strong friction, exposure suddenly to a heat equal to 368 of Fahrenheit, or the contact of sulphuric acid. It does not explode spontaneously, and is of course less dangerous than several of the other fulminating powders. Its initial force is much greater than that of gunpowder, but does not extend so far. It is from this property well adapted to the blasting of rocks.

Mr Howard, by analyzing this powder, found it to

* Philosophical Magazine, vol. xvi. p. 186.

consist of oxide of mercury, combined with oxalic acid, and nitrous etherized gas,—the two latter being produced during its formation, by the action of the nitric acid on the alkohol. It contains about 65 of mercury in 100 parts. Its explosion, and the force it exerts, he supposes owing to the oxygen present combining with the carbon and hydrogen, forming watery vapour and carbonic acid: nitrogen gas is also discharged, and much caloric is evolved so as to volatilize the mercury. It is to this latter cause principally, the conversion of the mercury into vapour, that Mr Howard ascribes its great explosive force; and his experiments shew that such a cause exists; since, when the detonation was performed in close vessels, a film of mercury covered their internal surface, and mercurial vapour, it is known, has a great elastic power *.

According to Berthollet, however, fulminating mercury does not contain oxalic acid, but ammonia and alkohol somewhat altered †.

Quicksilver combines with sulphur. When equal parts of them are triturated together, in a short time the mercurial globules disappear, nor can they be distinguished by the microscope, if the trituration has been sufficient. This, therefore, must be regarded as a real chemical combination: it is much promoted by heat, and is effected much more speedily merely by pouring the mercury into the sulphur melted.

This compound, formerly known by the name of Mineral Ethiops, is termed Black Sulphuret of Mercury, to

* Philosophical Transactions, 1800, p. 204.

† Philosophical Magazine, vol. xii. p. 92.

distinguish it from another compound, the Red Sulphuret. This is prepared by mixing one part of sulphur with from seven to eight parts of mercury, and by the application of a moderate heat causing them to combine. The black powder which they form is then exposed to a heat sufficient to inflame it : after the inflammation has ceased, the remaining mass is sublimed in close vessels. The sublimate is mercury in combination with sulphur : it is of a very fine red colour, and, when levigated, is in common use as a pigment, under the name of Cinnabar, or Vermilion. The colour of it is much more bright than that of the native cinnabar. The preparation of it is attended with considerable difficulty, at least as to the production of the fine red colour. Mr Tuckert and Mr Payssé have given the details of the process, as it is carried on in Holland, on a very large scale *.

Mercury decomposes the alkaline sulphurets, when these are dissolved in water, attracting the super-sulphuretted hydrogen, and forming a black powder, similar in its appearance to black sulphuret of mercury. These compounds, especially that precipitated from the sulphuret of ammonia, assume a red colour by long exposure to the air, probably from the absorption of oxygen, which combines with their hydrogen. This change is accelerated by trituration, and the application of a moderate heat, and on this principle a method has been proposed of forming cinnabar in the humid way. It consists in triturating mercury and sulphur with potash and water, the vessel being kept warm in a sand-bath. After two hours

* *Annales de Chimie*, tom. iv. and tom. li.

trituration, the colour changes from a black to a brown, it then passes rapidly to a red, and forms cinnabar *.

Both the black and the red compounds which quicksilver forms with sulphur have been supposed by some chemists to contain the metal in an oxidized state: and, according to Vauquelin, cinnabar owes its fine red colour to the large quantity of oxygen with which the mercury is combined †. This opinion, however, does not appear to be established by any decisive fact: and other chemists have therefore regarded them as pure sulphurets. According to Proust, cinnabar consists of 85 of mercury, with 15 of sulphur ‡. And according to Seguin, ethiops and cinnabar are mere compounds of sulphur and mercury in different proportions. The proportions in the first may be various; in the other they are determinate, being 86.7 of mercury, with 13.3 of sulphur ||. Berthollet had supposed that the black sulphuret contained a portion of sulphuretted hydrogen; but he has relinquished this opinion in consequence of the researches of Seguin ¶.

Mercury does not seem capable of uniting with carbon. It combines with phosphorus, though with much difficulty. To effect the combination, Pelletier employed the following process. Two parts of the red oxide, or sub-nitrate of mercury, and one and a half of phosphorus, were mixed together, covered with water, and heated in a

* Nicholson's Journal, 4to, vol. ii. p. 1.

† Ibid. vol. v. p. 311.

‡ Ibid. 8vo, vol. i. p. 112.

|| Philosophical Magazine, vol. xii. p. 279.

¶ Chemical Statics, vol. ii. p. 377.

glass-vessel. The phosphorus attracts the oxygen from the oxide : part of it is converted into phosphoric acid : another portion of it, as Pelletier supposed, combines with the reduced mercury. This phosphuret of mercury is a tenacious concrete substance, fusible at a high temperature, and at the same time easily decomposed.

Quicksilver combines with many of the metals. All these combinations are brittle or soft ; and if the quicksilver is in any considerable proportion, are more or less fluid : they are named Amalgams. It has not been found possible to unite it with iron, cobalt, or nickel, probably from the great infusibility of those metals, counteracting the weak affinity they may have to the quicksilver. It unites with difficulty with platina ; but when the precipitate from the solution of platina in nitro-muriatic acid is used, according to the process of Moussin Pouschkin, the union is effected more easily : the alloy is brilliant, and of a fine grain *. The combination with gold is effected with facility : the amalgam is more or less solid, according to the proportion of gold, and of a more or less deep yellow colour ; when solid it is easily fused, and crystallizes on becoming concrete, in quadrangular prisms or octaedrons. By a strong heat, the mercury is volatilized. Silver amalgamates with equal facility ; the amalgam varying in consistence according to the proportions, and being of a dull white colour. When solid, it is crystallizable. The specific gravity of the compound always exceeds greatly the mean specific gravities of the two metals, and has even been said to be su-

* Nicholson's Journal, 4to, vol. i. p. 539.

perior to that of quicksilver itself. From its property of amalgamating with gold and silver even in the cold, mercury is used to separate these metals from the substances with which they are mixed. It is thus capable of extracting the hundred-thousandth part of gold. In gilding and silvering, it is, from the same property, the medium of union between the gold or silver, and the metal on which the operation is performed.

Mercury is extensively used for these purposes. Its amalgam with tin is used in the silvering, as it is termed, of mirrors. By its application in the barometer, it has demonstrated the weight of the air ; and, from the regularity of its expansion, it is the best thermometrical fluid. In medicine it is extensively employed.

The mercury of commerce often requires to be purified : it is even frequently intentionally adulterated. Lead is added to it, and, in order that its fluidity may not be diminished, a quantity of bismuth. The adulteration is suspected, when its surface, after it has been strained through leather, tarnishes quickly ; when it does not divide readily into globules ; or when these do not preserve exactly the globular form, nor unite readily when brought near to each other. It can be detected with certainty by heating it in an iron-spoon, when, if any metal be present, it will be the residuum. It is purified by distillation with iron-filings, as has been already stated.

CHAP. IX.

COPPER.

THIS metal is of a red colour, with a shade of yellow. It is inferior in lustre, malleability, and ductility, to the more precious metals. Being much more abundant, and being easily cast and worked, it is applied to many useful purposes, and its value would be still greater, were it not acted on by air and moisture, and were it not in particular noxious to health. It is found in many countries in considerable quantity, and is one of those metals which were of earliest discovery. It exists native and mineralized by oxygen, by sulphur, either alone or in combination with iron, arsenic, antimony, and other metals, and by a number of the acids.

The sulphurets are the ores from which the copper is usually extracted. The ore is roasted by a low heat in a furnace with which flues are connected, leading to a chamber in which the sulphur that is volatilized is collected. The remaining ore is then smelted in contact with the fuel; the iron present in the ore, not being so easily reduced or fused as the copper, remains in the scoria: the copper is run out; it often requires repeated fusions, and even after these, is still alloyed with portions of those metals which may have been present, which are not volatile, and are of easy fusion. Hence, the copper of commerce is never altogether pure, but generally

contains a little lead, and a smaller portion of antimony. The carbonates of copper reduced by fusion, in contact with the fuel, afford a purer copper ; as does also the solution of sulphate of copper which is met with in some mines, the copper being precipitated in its metallic state, by immersing in it old iron ; the precipitate of copper is then fused. The processes for making copper ore followed in Anglesea and Cornwall, are well described in Aikin's Chemical Dictionary, under the article Copper.

Copper has a specific gravity, when merely fused, of 7.78 ; when hammered, of 7.87. In hardness, it is inferior to iron and platina, but superior to the greater number of metals. Its ductility is such, that a wire, one-tenth of an inch in diameter, can support, without breaking, a weight of 299 lbs. Its malleability is such, that it can be beat into very thin leaves. It has a sensible odour when rubbed, and its taste is disagreeable and metallic.

To melt copper, it requires to be exposed to a strong white heat, or, according to Guyton, a temperature equal to 27 of Wedgwood. If slowly cooled, it may be obtained in crystals, which are single or double tetraedral pyramids. By a more intense heat it is volatilized.

If copper be heated in contact with atmospheric air, even below the temperature of ignition, its surface exhibits various ranges of prismatic colours, which, as the heat is continued, change quickly,—appearances probably owing to incipient oxidizement. When the temperature is raised to ignition, the oxygenizement becomes more rapid, thin scales of a brown colour forming on its surface. These are easily detached, by dipping the copper in cold water : when exposed to a continued heat, they become of

a deep-red colour, probably from the continued absorption of oxygen. When copper is at once exposed to a very high temperature, it burns with a green-coloured light. This is very bright when the copper is placed in a kindled stream of oxygen and hydrogen gasses : it is also exhibited when the copper is subjected to a red heat with nitre.

There is some obscurity with regard to the oxides of copper, though the subject has been investigated by Proust and Chenevix. The latter chemist supposed, that the metal, in the first degree of oxidizement, is not obtained by the action of atmospheric air on it at a high temperature, but exists in some of its saline combinations, from which it may be separated ; as, for example, dissolving copper in muriatic acid, with the assistance of heat, adding to the solution a portion of metallic copper, and excluding for some time the access of the air. The solution becomes of a dark-brown colour. On pouring it into a solution of potassa, an orange-coloured precipitate is thrown down, which is regarded by Mr Chenevix as the oxide of the first degree of oxidizement, and is composed of 88.5 of copper, with 11.5 of oxygen *. This oxide, he found, forms the principal part of the red copper ore.

Proust supposed that the metal exists in a higher degree of oxidizement; the oxide being of a very dark brown or a black colour, and, according to his analysis, consisting of 75 of copper, with 25 of oxygen. It is formed when copper is oxidized by atmospheric air at a high temperature ; the scales formed on the surface of the metal, consisting of about 62 of this oxide, with 38 of metallic

* Philosophical Transactions, 1801, p. 235. 237.

copper, which, however, may be also oxidized, when the application of a red heat is continued for some time to the scales reduced to powder. The same oxide is precipitated from the salts of copper, and is obtained by exposing the precipitate to a heat sufficient to expel the water in combination with it *.

From the salts of copper, precipitates are thrown down by the alkalis, and some of the earths, which are of a green or blue colour, of various shades, and which were formerly regarded as oxides. According to Proust, the green is a sub-salt, or an oxide with a small portion of acid, and a quantity of water; the blue, a compound of the black oxide, with water alone, or, as he names it, a Hydrate of Copper. This water is in the proportion of 24 in 100 parts: he considers it as in a state of intimate chemical combination, and as the cause of the blue colour; and this hydrate, he supposes to be the immediate base of a number of the salts of copper. These opinions were adopted by Mr Chenevix, in his researches on the arseniates of copper †. Berthollet *junior* has shewn, however, as I shall immediately have to remark, that the blue precipitate, supposed to be a combination of oxide of copper with water, is a sub-salt, or an oxide with a small portion of acid. In its different solutions, copper exhibits various colours, as well as in the precipitates which are obtained from the decomposition of these solutions; and it is probable that, like the greater number of the metals, it is susceptible of various degrees of oxidizement.

* Annales de Chimie, tom. xxxii. p. 26.

† Philosophical Transactions, 1801.

Copper, at its maximum of oxidizement, is semi-vitrified by a strong heat, acquiring lustre, and a deep red colour. None of its oxides are decomposed by heat alone; but at a high temperature, charcoal, and substances containing carbonaceous matter, attract the oxygen.

When exposed to humidity, and to the action of air, its colour not only tarnishes, but it is soon covered with a green efflorescence or crust. This, according to Proust, is a carbonate of copper.

Copper is acted on with facility by the greater number of the acids, and saline combinations are formed almost all of them soluble and crystallizable, and generally either of a green or blue colour. Ammonia throws down from them a blue precipitate, and, added in excess, re-dissolves it, forming a transparent solution of a very deep blue colour. Iron, immersed in any of these solutions diluted, precipitates the copper in its metallic state.

Sulphuric acid, when concentrated and aided by heat, oxidizes and dissolves copper; and when diluted, acquires from it even in the cold a blue colour, indicating that a portion is dissolved, the copper being oxidized probably at the expence of the water. The sulphate of copper is abundantly soluble in water: by evaporation it can easily be obtained crystallized: the form of the crystals is that of a rhomboidal prism; their colour is a rich blue: they are at first transparent, but they become somewhat opaque, from a slight efflorescence on exposure to the air: they are soluble in about four parts of water at 60° , and in two parts at 212° ; the taste of this salt is harsh and styptic, and it possesses a degree of corrosive power. It is the Blue Vitriol of commerce, and is generally formed,

not by the solution of copper in sulphuric acid, but is either crystallized from the solution of it found in some copper-mines, or is formed by roasting copper pyrites, and exposing the residual matter to the action of air and humidity : by the roasting the sulphur is partly dissipated, and the relative increase thus effected in the proportion of metal, favours the oxidation of the compound. Sulphate of copper is thus slowly formed, and is extracted by lixivation and crystallization.

Sulphate of copper is decomposed by heat. It first fuses from the heat communicated to its water of crystallization : this is dissipated, and a light blue powder remains, which, urged by a stronger heat, gives out its sulphuric acid, the oxide of copper remaining of a black colour. From the analysis of this salt performed in this mode, Proust infers, that its constituent parts are black oxide of copper 32, sulphuric acid 33, and water 36 *. This agrees nearly with the estimate before made by Mr Kirwan, in which the proportions had been stated at 40 of oxide, 31 of acid, and 29 of water. The water which is expelled by heat, is not, according to the views of Proust and Chenevix on the salts of copper, water of crystallization, but combined with the oxide of copper, forming a hydrate ; and according to the latter chemist, sulphate of copper is composed of 42 hydrate of copper, 33 of acid, and 25 of water.

This salt suffers a partial abstraction of its acid, by the alkalis or earth. Thus potassa added to its solution, taking care to avoid adding it in excess, throws down a precipitate of a green colour, which may be washed with

* *Annales de Chimie*, tom. xxxii. p. 33.

water to carry off any adhering neutral sulphate. This precipitate is a sub-sulphate, and consists, according to Proust, of 68 parts of black oxide of copper, 14 of water, and 18 of sulphuric acid. Ammonia throws down from the sulphate, as it does from all the salts of copper, a precipitate of a greenish or blue colour according to the quantity, and when added in excess, it re-dissolves this, forming a solution, transparent, and of a deep blue colour.

Sulphurous acid, though incapable of directly dissolving copper, combines, according to the researches of Fourcroy and Vauquelin, with its oxide; or the combination may be more easily effected, by adding a solution of sulphite of soda to a solution of sulphate of copper, the salts exchanging their principles. A yellowish precipitate is first formed, and afterwards crystals are deposited of a greenish white colour: these differ in the proportion of copper, the former containing an excess of oxide; the latter is the sulphite of copper: it is sparingly soluble in water, is decomposed by heat, and by the affusion of concentrated sulphuric acid, sulphurous acid gas is disengaged.

Nitric acid acts on copper with rapidity. Even in the cold a large quantity of nitric oxide gas is disengaged with effervescence. When the acid is diluted, a similar production of nitric oxide takes place, especially when its action is promoted by the application of heat. The oxide, as it is formed, combines with a portion of the acid, and a solution is formed of a green or blue colour, probably according to the degree of oxidizement; a portion of a yellowish-brown powder generally remaining undissolved. By evaporation, this solution affords prismatic crystals of a blue colour: these are abundantly soluble in water, and are deliquescent: exposed to heat, nitrous acid vapour

is exhaled, as soon as the salt is in fusion, and the greater part of the acid is thus decomposed or disengaged.

This salt, from the facility with which it parts with oxygen, is capable of acting with energy on a number of substances. It detonates slightly when thrown on burning fuel; and when struck with phosphorus, detonates more loudly. It is also capable of burning some of the metals: A singular action of this kind, which it exerts on tin, has long been known. If a quantity of the crystallized salt in powder, in a humid state, be wrapped up in tinfoil, nitrous acid vapour is almost immediately disengaged; the temperature rises, and the metal is inflamed, owing to the transfer of the oxygen from the copper to the tin, this latter metal having a strong attraction to oxygen, and combining with a large quantity of it.

Nitrate of copper is decomposed by the alkalis, with results similar to those observed in the same decompositions of sulphate of copper, but which require distinct notice, as having given rise to the opinion of Proust and Chenevix, already stated, of the intimate combination of water with oxide of copper. When potassa or soda is added to a dilute solution of nitrate of copper, a blue precipitate is at first formed, which becomes, however, green when the mixture is agitated, and when an excess of alkali has not been added. If, on the other hand, the nitrate is added to the solution of potassa much diluted, a precipitate is obtained of a bright blue colour. The green precipitate, according to Proust, is a sub-nitrate of copper. Sulphuric acid disengages from it nitric acid, as does also the application of heat. It differs in nothing from a sub-nitrate which is obtained by distilling nitrate of copper in

a glass-retort, until it form a thick insoluble matter, and which, according to Proust, consists of 67 of black oxide of copper, 16 of nitric acid, and 17 of water. If the application of heat be continued to it, or if it be boiled with a solution of potassa, the whole of the acid is abstracted, and it is brought to the state of the black oxide.

The blue precipitate, it has already been remarked, is regarded by Proust as oxide of copper, combined with a considerable proportion of water,—14 or 15 parts in 100 : and it is equally obtained from the other salts of copper by decomposing them, by the addition of a sufficient quantity of alkali. To obtain it pure, it is necessary to dilute it in a large quantity of boiling water, to withdraw the water by filtration, and wash the precipitate largely. It is then of a fine blue colour. If spread out on paper, and heated until the temperature is above 212° , it loses its colour, becomes green, and at length is converted into the black oxide,—a change ascribed to the loss of its water. 100 parts of it distilled give 24 of water, 75 of black oxide, and about a grain of carbonic acid which may be regarded as accidentally contained in it. This substance, though permanent in the air, decomposes gradually when kept under water. It dissolves with facility in acids. It is also stated to be dissolved by a strong solution of potassa, and very readily by ammonia. This hydrate of copper Proust supposes to exist in nature, and to be the base of the blue copper ore. It is also regarded by Mr Chenevix, as has been already stated, as the base of the greater number of the native arseniates of copper.

The principal reason that Proust gives, independent of its analysis by heat, (in which the possibility of an error

must be admitted), for believing that this substance contains no acid, is, that none is abstracted from it by potassa, which abstracts even the carbonic acid from metallic oxides, and must therefore still more abstract the acids to which it has a stronger affinity. But this argument is altogether inconclusive, since, from the influence of quantity, a portion of acid may be retained by the oxide, which the alkali cannot remove, and since in other metallic sub-salts this is actually the case. Berthollet *junior* has examined this substance *, and has clearly shewn, that, as obtained from the different salts of copper, it retains a portion of the acid of the salt, and is equally a sub-salt with the green precipitate, differing from it only in the proportion of acid being less. Thus, the sulphuric being an acid which is most easily detected by re-agents, he precipitated sulphate of copper by potassa, washed the precipitate with great care, and dried it slowly. On dissolving 100 parts of it in muriatic acid, and adding muriate of barytes, a precipitate was afforded, which indicated the presence of seven parts of sulphuric acid. In like manner, when the blue precipitate is digested with an alkali until it lose its colour, the alkali, saturated with muriatic acid, gives a precipitate with muriate of barytes of the same weight as the preceding, and the black oxide remaining weighs 72 parts from 100 of the precipitate. Hence the blue precipitate, analysed in this way, the hydrate of copper of Proust, consists of 72 oxide of copper, 7 of sulphuric acid, and 21 of water. The green precipitate from sulphate of copper, it has already been remarked, contains 18 of acid, and 14 of

* Chemical Statics, vol. ii. p. 484.

water. When the blue precipitate was decomposed by heat, in the manner that Proust made his analysis, a portion of acid was found retained by the oxide, which was detected by dissolving this oxide in muriatic acid, and adding muriate of barytes. And Berthollet has also shewn, that by merely boiling this precipitate strongly and repeatedly in water, a part, though not the whole of its acid, may be abstracted, and it changes its colour from a blue to a brown.

The blue precipitates from the other salts of copper, this chemist found equally to contain portions of the respective acids. Those obtained from the nitrate and muriate of copper, exposed on burning fuel, exhaled vapour, as they did also from the affusion of sulphuric acid, which indicated the presence of the nitric and muriatic acids. The precipitate from the muriate of copper, dissolved in nitric acid, gave a precipitate too with nitrate of silver.

These experiments must be regarded as decisive, and the existence of the hydrate of copper of Proust is disproved. It may be added, however, that there appears reason to believe, that oxide of copper has a stronger affinity to water than most of the metallic oxides; as the precipitates of its salts, even in their dry state, retain more of it than those of the others do, and as it exists in considerable quantity in several of the native combinations of copper. But it is not very probable that this communicates to the oxide any very distinctive properties.

The precipitate obtained from nitrate of copper by lime, levigated with the addition of from 5 to 10 of lime in 100 parts, forms the paint known by the name of Verditer.

Muriatic acid dissolves copper slowly when the atmospheric air is admitted, and with more facility when its

action is promoted by a moderate heat, hydrogen gas being in the latter case disengaged. The solution is of a green colour. A similar solution, more concentrated, is obtained with more facility by adding oxide of copper to muriatic acid. The solution is of a very deep green, and by evaporation affords slender prismatic crystals of a grass-green colour. This salt is acrid, and capable of acting as an escharotic : it is deliquescent, and very soluble in water. It is fused with a moderate heat, and by an increase of heat may be decomposed : the acid receiving a portion of the oxygen of the oxide, is disengaged in the state of oxy-muriatic acid ; while the copper remains at a low state of oxidizement, still retaining a portion of acid.

This salt is decomposed by the alkalis, nearly in the same way as the other salts of this metal. Potassa added to its solution first throws down a green precipitate, which, by the farther action of the alkali, may be rendered blue ; these precipitates, according to the preceding view, being sub-muriates of copper.

Proust, estimating the quantity of oxide which muriate of copper contains, from the quantity of oxide obtained by the action of potassa, and of acid, by the precipitate afforded by nitrate of silver, infers that it consists of 40 parts of the black oxide, 24 of acid, and 36 of water.

Besides this, there are other combinations of copper with muriatic acid, the metal being in other states of oxidizement. If a quantity of copper-filings be added to a solution of green muriate of copper, and the phial closed so as to exclude the atmospheric air, the green colour gradually disappears, and the solution is rendered nearly colourless : the metallic copper has, therefore, shared the

oxygen of the oxide of copper, which was in combination with the acid. But that a portion, at least, of this imperfect oxide, is still in solution, is evident from the fact, that on admitting the atmospheric air the liquor regains its colour, and the tint appears first at its surface. This denotes, therefore, a combination of copper in a low state of oxidizement with muriatic acid. Chenevix found, too, that by mixing the black oxide of copper, the base of the former salt, with nearly its own weight of metallic copper precipitated from its solution by iron, on adding to the mixture muriatic acid in a phial accurately closed, the whole nearly was dissolved, the residuum being such a portion of metallic copper, that the dissolved matter had consisted of equal weights of copper in this state, and of the black oxide. Of course, as the former could receive the oxygen necessary to its combination with the acid only from the latter, the whole must have been in a low state of oxidizement: the liquor was of an orange-brown colour. And Proust had before discovered, that recently prepared muriate of tin, added to a solution of muriate of copper, deprives it of a portion of its oxygen, and a white muriate of copper is formed *. This muriate is also produced, according to Berthollet *junior*, merely by adding a little water to the brown muriate of copper, which, by the affinity of the water, is made to pass to two states of oxidizement, that forming the white muriate which is precipitated, and a blue muriate which remains dissolved, giving its colour to the solution. Thus there are the white, brown, and green muriates of copper, in which the metal exists in different degrees of oxidize-

* *Annales de Chimie*, tom. xxviii. p. 218.

ment, and it is not improbable that there may be still others than these. The white muriate has, at the same time, probably a deficiency of acid which renders it insoluble; for an addition of acid dissolves it, forming a colourless solution*.

Oxymuriatic and nitro-muriatic acids dissolve copper, the metal being highly oxidized; and as the solution proceeds in the latter acid, a green powder is precipitated, which, according to Proust, is a sub-muriate. Perhaps also an oxymuriate exists; as Chenevix found, that on passing oxymuriatic acid gas through water in which oxide of copper was suspended, the oxide was dissolved.

The other acids, though they do not easily dissolve copper, at least so as to produce saturated compounds, are capable of combining with its oxides. These combinations are most easily obtained, by adding to a solution of nitrate of copper, any compound salt, containing the acid with which the oxide of copper is designed to be combined. Thus, the precipitate thrown down, on adding a solution of carbonate of potassa to a solution of nitrate or sulphate of copper, is carbonate of copper. When there is no excess of acid or of alkali, it is insoluble, and of a fine green colour. It is decomposed by heat: from the products of its decomposition, Proust states its composition at 70 of black oxide of copper, 25 of acid, and 5 of water. The Phosphate of Copper, obtained by a similar process, is in the form of a greenish precipitate. It consists, according to Chenevix, of 49.5 oxide of copper, and 12 of water, combined with 35 of

* Chemical Statics, vol. ii. p. 491.

acid, and 3.5 water of crystallization. The Borate of Copper is of a similar colour, and very little soluble. The Fluuate can be formed by the immediate solution of oxide of copper in fluoric acid, and can be obtained crystallized.

With some acids which have not yet been considered, oxide of copper likewise combines, as with the arsénic acid, forming a compound of a fine green colour, used as a paint under the absurd name of Vegetable Green, and with the acetic acid forming verdigrease. These combinations are to be afterwards noticed.

The alkalis, it has already been remarked, decompose the salts of copper by abstracting the greater part of the acid. Ammonia added in excess redissolves the oxide, forming with the acid a ternary compound. It can also combine directly with the oxides of copper. If the metal be highly oxidized, the solution is of a very deep blue colour: if it is at an inferior degree of oxidizement, the solution is colourless. This is proved by an experiment similar to that which has been already stated with regard to the muriate of copper. If ammonia be poured on copper-filings, and exposed to the air, it acquires a blue colour; but if the phial containing them be closed, the colour of that portion of the liquid immediately above the undissolved copper becomes fainter: this proceeds upwards, and the whole at length becomes colourless. If the air be now admitted, in a few minutes the surface of the liquid assumes a blue tint, which deepens and extends through the whole liquid. The metallic copper in the first stage of the experiment attracted part of the oxygen of the oxide of the blue solution; and the oxide in combination with the ammonia, being thus in a low state

of oxidizement, formed the colourless solution. On exposure of this to the air, the oxide dissolved immediately attracts a portion of oxygen, and the blue colour is reproduced. The compound of ammonia, and oxide of copper, it has been affirmed, may be obtained in a crystallized form. These crystals, however, are rather a triple salt, obtained either by the slow evaporation of the liquor, formed by adding ammonia in excess to sulphate of copper, or by adding to it alcohol, by which minute crystals are deposited. A preparation of this kind is employed in medicine, under the name, not strictly correct, of Ammoniuret of Copper. It is prepared by triturating two parts of sulphate of copper with three parts of carbonate of ammonia: an effervescence takes place from the disengagement of the carbonic acid: the mass becomes soft and humid, and when dried forms a crystalline powder of a deep violet colour. It is the triple compound of oxide of copper, ammonia, and sulphuric acid. When muriate of ammonia is digested on copper-filings, with the free access of atmospheric air, the copper is oxidized, and the triple compound of oxide, ammonia, and muriatic acid, is formed. A pigment is thus prepared, named Brunswick Green.

The fixed alkalis exert less action on copper or its oxides. It has been said, that their solution digested on copper-filings, acquires a blue tinge; but the fact is doubtful: and Vauquelin found, that the perfect oxide of copper is not dissolved in perceptible quantity by potassa,—a property on which he founded a method of analysing brass, to be afterwards explained. Carbonate of potassa dissolves oxide of copper, forming with it a ternary combination.

Copper has been generally stated not to form any combination with carbon. Priestley had observed, however, that in passing the vapour of alcohol through a copper tube, at the temperature of ignition, a substance was formed, black and friable, which he named Charcoal of Copper. This subject has been farther investigated by Van Marum. He put copper-wire in an earthen tube, which was raised to a red heat, while the vapour of alcohol passed over it: a large quantity of carburetted hydrogen gas was formed, and the copper-wire was incrustated with a black matter. And in a second experiment, by passing a larger quantity of alcohol in vapour through the tube, the whole of the copper-wire that had been at a red heat was converted into a similar matter, 1040 grains being obtained from 748 grains of copper, which was a larger proportion of copper in the compound than was obtained by Priestley. This matter Van Marum found to be inflammable: it burnt vividly in oxygen gas, affording carbonic acid: the residual matter was partly oxide of copper, partly charcoal, these being separated by nitric acid, which dissolved the former. From these experiments, Van Marum regards this substance, with Priestley, as a carburet of copper*.

Copper combines readily with sulphur by fusion. If three parts of copper-filings, with one part of sulphur, be heated in a glass-matrass, as soon as the sulphur is in fusion, their combination commences, and is attended with a rich glow of red light. The sulphuret of copper which is thus formed, is of a dark colour, sometimes variegated,

* *Annales de Chimie*, tom. xxx. p. 322-8.

with a degree of metallic lustre, and exhibiting somewhat of a crystalline structure : it is brittle, and more fusible than the metal. Its properties vary a little, according to the proportion of sulphur. The combination may likewise be effected by stratifying thin copper plates with sulphur in powder, and applying a gradual heat.

Sulphuret of potassa combines with copper, either by fusion, or by boiling its solution on copper-filings. Sulphuretted hydrogen, and the hydro-sulphurets, throw down a precipitate of a dark brown or black colour from the salts of copper.

Copper can be combined with phosphorus with facility. Margraaf had effected the combination by exposing to heat an oxide of copper with phosphorus ; but the process of Pelletier, that of heating in a crucible equal parts of copper in thin pieces, and of phosphoric acid, with $\frac{1}{16}$ of powdered charcoal, succeeds better. This phosphuret is of a white colour, with a shade of grey, and a metallic lustre, which is impaired by exposure to the air, passing at length to a black colour. By projecting pieces of phosphorus on copper in fusion, Pelletier obtained a phosphuret of a very white colour, and a great degree of hardness. The copper had increased in weight 15 parts in 100 *. Sage, by exposing to heat two parts of phosphoric acid, with one of copper, and a twelfth of charcoal, obtained a phosphuret in which the phosphorus had increased one-twelfth of its weight. It was of a grey colour ; with much brilliancy ; susceptible of a fine polish ; and of the hardness of steel. It did not lose its lustre

* Mémoires de Chimie, tom. i. p. 274. tom. ii. p. 32.

from exposure to the air, nor suffer any change for a number of years *. These phosphurets are more fusible than the metal. Exposed to a continued heat, a great part of the phosphorus is volatilized and burnt at the surface.

Copper is capable of combining with the greater number of the metals by fusion, and some of its alloys are important from the qualities they possess. It has already been stated, that, alloyed with gold, it rather deepens than impairs the colour of the gold; and if pure, and not in too large a quantity, it does not much lessen the ductility, while it gives greater hardness. The specific gravity of the compound is greater than the mean of that of the two metals. Standard gold is an alloy of one part of copper in twelve of the mass. With silver it also unites with facility: in this case the specific gravity is less than the mean, or there is an expansion from the combination instead of condensation, probably from the crystalline arrangement which the particles of the alloy assume. A greater degree of hardness is also acquired. The colour of the silver is not much altered, when the proportion of copper is not large. The standard silver of this country contains one part of copper in sixteen of the mass. Copper, fused with platina, combines with it. When the proportion of platina does not exceed one part in four or five of the compound, the alloy is ductile, of a close grain, and susceptible of a fine polish, while its lustre is not liable to tarnish. A compound of this kind, with the addition of a little arsenic to render it more fusible, has been used for constructing the mirrors of reflecting

* Nicholson's Journal, vol. ix. p. 267.

telescopes. With quicksilver, copper in thin leaves amalgamates by trituration; and quicksilver applied to the surface of copper, instantly whitens it, and, kept applied, renders it brittle. The other alloys of copper are to be afterwards noticed. With zinc it forms brass and pinchbeck; with tin, bell-metal, and bronze.

Copper, besides being used extensively under the form of its alloys, is in its pure form applied to many useful purposes, as it is ductile and easily wrought. It is formed into thin sheets by being heated strongly in a furnace, and subjected to pressure under steel rollers. These sheets being both light and ductile, are applied to a number of uses, as to the sheathing the bottom of ships, &c. and to the covering the roofs of buildings. For this last purpose it is not well adapted, as it is so highly sonorous, and also from its expansibility and rigidity becomes elevated and unequal, from the effect of heat. For sheathing the bottoms of ships it is preferable to every metal, as it can be made to adhere better, is less liable to wear, and prevents more effectually the adherence of marine animals. It is used in the construction of stills and boilers. It is also fabricated into a variety of household utensils, the use of which, however, for preparing or preserving articles of food, is far from being free from danger, since copper is liable to oxidizement by atmospheric air, when moisture is at the same time present, and since any substance, even in a slight state of acidity, will act on it still more quickly. From this cause fatal accidents have often arisen from the impregnation communicated to liquors from copper vessels. The danger has been attempted to be obviated by tinning the copper, or applying to its surface a thin

covering of tin ; but this is liable to be soon eroded, and may even prove more dangerous from a slight erosion not being perceived, and less care being taken, on the supposition that the copper is covered by the tin. It has been proposed, as has been already mentioned, to apply a covering of platina, by applying to the surface of the copper an amalgam of platina, and exposing it to the heat of ignition, repeating the operation a second time, to render the coating more perfect *. This would no doubt be less liable to wear. Several of the combinations of this metal are used as paints, and some of its preparations are employed in the practice of medicine.

CHAP. X.

IRON.

THIS well-known metal, the most useful of the whole class, and the most indispensable to man, is more abundantly diffused through nature than any other. It is found in the earth combined with other substances, earthy and metallic, and under a variety of forms : there are even few fossils entirely free from it ; and it is the principle on which their colours very generally depend. It is often present in the water of springs. It is contained in a number of vegetable products, and is obtained from their ashes when they are burnt : and it is a constituent principle of the blood, and of several other animal fluids and solids.

* Nicholson's Journal, vol. ix. p. 303.

It is the principal ingredient, too, of those masses which occasionally fall from the atmosphere, the meteoric stones, as they have been named. In the mineral kingdom, it is mineralized by oxygen, forming a very extensive family of ores, in which the oxide is more or less pure, or intermixed with other substances. It is farther mineralized by carbonic, phosphoric, and arsénic acids; and abundantly by sulphur, forming the mineral denominated Pyrites. The ores which are wrought to extract the metal, are the different varieties of the oxides. The process varies, as carried on in different countries, and as adapted to different ores; but the following is the general outline of it, especially as it is conducted in this country, on the hæmatite, and the different varieties of argillaceous iron stone, the ores which with us are principally wrought.

The ore is first roasted with a strong heat, to expel the carbonic acid, any sulphur, or other volatile matter that may be present. The remaining ore is put into a furnace of a conical form, with charcoal, or rather with coal coaked, and is exposed to a heat, excited and rendered sufficiently intense by a blast of compressed air urged through the furnace. A quantity of lime is at the same time added to the ore, and fuel; the advantage of which appears to be, that in combination with the argil and silex, so generally contained in the iron ores, it acts as a flux to vitrify the scoria, and facilitate the separation of the melted metal. The proportions of these are extremely various, according to the nature of the ore. The quantity of lime is about as 1 to 4, or 5 by weight of the coaked coal, and the proportion of ore must vary according to its richness, and according to the substances with which the oxide of

iron is mixed in it ; generally it is about $3\frac{1}{2}$. When the furnace is once charged, the charge is renewed at the upper part as the materials sink, and the process is carried on for a long time without interruption. The slag or scoria are drawn off by an opening towards the bottom of the furnace. There is a cavity at the bottom, in which the melted metal is collected, and from which, as it accumulates, it is run off at intervals into moulds*.

The metal thus obtained is named Pig Iron, Crude or Cast Iron. It is far from being pure, it contains always more or less oxygen and carbon ; the oxygen being partly a portion of what was originally combined with the metal in the ore, and partly perhaps derived from the strong blast of compressed air driven through the contents of the furnace, and necessarily presented to the metal as it is reduced and fused, the carbon being derived from the fuel. Other substances are also often contained in it, particularly phosphorus, chrome, manganese, silex, and argil ; all of which Vauquelin, in a late memoir, has shewn to exist in crude iron, and some of them also in bar iron†. Some of these may be in immediate combination with the iron, or even mechanically mixed with it. The oxygen, carbon, and phosphorus, there appears some

* Account of the manufacture of iron by Mr Collier, Manchester Memoirs, vol. ii. ; and by Mr Muschet, Philosophical Magazine, vol. ii. A very full account, too, of the processes for extracting and working iron, as carried on in this and other countries, is given in Aikin's Chemical Dictionary, under the history of this metal.

† Nicholson's Journal, vol. xxi. p. 39.

reason to believe, exist in the state of an oxide, carburet, and phosphuret of iron, combined with the mass of iron.

From these foreign substances, the qualities of cast iron are very various. Three kinds of it have been principally distinguished, though they pass insensibly into each other,—the white, the grey, and the black. The first is of a white colour, which is best displayed in a fresh fracture: the fracture exhibits also an appearance of striæ, or indistinct crystallization; and its surface is oxidized: it is extremely brittle. In commerce, this substance is named White Crude Iron; and it is supposed to derive its qualities from a portion of oxygen, or rather perhaps of oxide of iron contained in the metal. The second is of a light grey colour: its fracture is granulated and dull; and it is less brittle than the former. This, which is the grey crude iron of commerce, is supposed to contain both oxygen and carbon. There is, lastly, the Black Crude Iron, the fracture of which gives a dark grey colour, inclining to blue, and presents granular concretions. This is supposed to contain principally carbon or carburet of iron combined with the metal. It is softer, and also more fusible than the others. The production of these varieties depends principally on the quantity of carbonaceous matter employed in the reduction, relative to that of the ore, and partly also on the kind of ore. Hence a considerable degree of practical skill is required in assorting and mixing the different ores. Much also depends on the management of the blast of compressed air.

Iron in any of these states is much more fusible than when pure; hence it is capable of being melted, and cast into moulds, so as to form vessels of any form. It is also,

however, much more brittle and hard, so much so, that it cannot be flattened under the hammer, or wrought; hence it is altogether unfit for many purposes to which pure or malleable iron is from its tenacity and softness well adapted.

To obtain pure iron, in other words, to free crude iron from the oxygen, carbon, and other foreign substances contained in it, it is subjected to two operations,—melting and forging; the operation being performed generally on white or on grey crude iron. The fusion is performed in a furnace. The melted metal is either run out to free it from the scorixæ which have separated, and is repeatedly subjected to this, until it attain a degree of malleability, when it is submitted to the action of the forge hammer: Or the metal is kept in fusion in a furnace, and while liquid is stirred frequently to facilitate the combination of the carbon and oxygen: a lambent blue flame at length appears on its surface, probably from the formation and disengagement of carbonic oxide. After some time its fluidity diminishes, and it at length assumes the consistence of a stiff paste. It is then subjected to the action of a very large hammer, or to the more equable, though less forcible, pressure of steel rollers, by which a portion of oxide of iron, and any other heterogeneous substances not consumed during the fusion, are forced out. The iron in this state is no longer granular in its texture: it is soft, ductile, and malleable, and much less fusible. It is then named Forged Iron, or Bar Iron, as it is generally formed into small bars. A considerable loss of weight attends the process, partly from the dissipation of the foreign substances, partly from the oxidize-

ment which the iron in part suffers. Vauquelin examined the sublimed matter collected in the chimneys of the refining furnace; he found, that in this sublimed iron are present oxide of manganese, silice, phosphoric acid, and a great deal of chrome; and in the scoræ of the same iron-works he discovered the same substances, with argil and lime*.

Forged iron is not, however, uniform in its qualities. On the contrary, there are several varieties of it which differ much from each other. Pure iron is distinguished by its very difficult fusibility, its softening when heated, so that two pieces can be joined together, and its great ductility and malleability. There is one kind of forged iron, which, when cold, has the ductility of the pure metal, and is even soft; but when heated, it is so fusible and brittle, that it is incapable of withstanding the stroke of a hammer. This is termed Hot Short Iron. There is another variety possessed of precisely the opposite property: it sustains the most violent heat without exhibiting any sign of fusion: while hot it is highly ductile, and may therefore be extended under the hammer into any form; but when cold it is extremely brittle, even more so than crude iron. This has been named Cold Short Iron.

The causes of these peculiarities in these two kinds of forged iron have not been fully discovered. An opinion advanced by Bergman has been generally received by chemists, that the cause of the property of cold short iron is the presence of what he regarded as a peculiar metal, and named Siderite, but which has been found to

* Nicholson's Journal, vol. xxi. p. 32.

be a phosphuret, or, as some have said, a phosphate of iron. This added to malleable iron gives it the cold short property; and those ores, it has been said, which produce this kind of iron, are those in which traces of phosphoric acid can be discovered. It has been affirmed, however, that every kind of malleable iron may, by peculiarities in the management of the refining process, be made to afford cold short iron, and that the quality arises from some peculiar combination of oxygen with the metal. Still less is known with regard to the nature of hot short iron. The peculiar property belonging to it has been ascribed to the presence of carbon, of sulphur, or sulphurous acid, or of arsenic, and also according to Vauquelin of manganese and chrome; but none of these opinions is well established.

Forged iron, free from these peculiarities, or the metal in its pure state, is malleable and ductile, and is extremely infusible.

There is one other state in which it exists, that of steel, distinguished by the extreme hardness and elasticity which it can acquire. This is a combination of iron with carbon, and is to be noticed as such.

The colour of this metal is a light grey, with a shade of blue: its texture is fibrous; its fracture is brilliant and fine grained: its specific gravity at a medium 7.700. Its hardness is superior to that of the other metals: it is very malleable, and exceedingly ductile, so that a finer wire can be drawn from it than from any other metal. It can also support in this state a greater weight without breaking; a wire 0.078 of an inch in diameter, supporting 549 lbs. It is highly elastic. By mere hammering it

may be brought to the temperature of ignition, from the quantity of caloric rendered sensible.

Iron is distinguished from all the other metals, by its magnetical property : it is attracted by the magnet, and it acquires itself the power of magnetism, by friction, by being suspended in a perpendicular direction, by the action of electricity, and of various other causes. It has been supposed, that it is the only substance in nature which possesses this singular property ; since, in whatever other metal or fossil it has been observed, iron, it is alleged, has been detected in their composition ; and, in proportion as the iron is abstracted from them, their magnetical power is diminished. This, however, has been denied ; and cobalt and nickel have been regarded as metals to which this singular property likewise belongs. The magnetic quality of iron is lost in some of its combinations, while it remains in others. It continues, though the metal be oxidized, until the quantity of oxygen exceed 20 parts with 80 of iron, and according to the experiments of Darso, remains when the metal is in a much higher state of oxidation, if the oxide is in a certain state of aggregation, or its particles are much approximated *. Mr Lane has shewn that the smallest quantity of inflammable matter, brought into combination with oxide of iron by heat, increases, and in some cases develops its magnetic power ; and he has even concluded, that pure oxides of iron, free from inflammable matter, are not magnetic †. Carbon, it is well known, enables iron

* Nicholson's Journal, vol. xvii. p. 330.

† Philosophical Transactions, 1805.

to retain the magnetic influence, as is exemplified in steel. When combined with sulphur to a certain extent, that of 36 with 64 of iron, the compound has a strong magnetic polarity, and retains this power, so that the mass acts as a permanent magnet, as Mr Hatchet ascertained*: combined with 45 or 46 parts, it is capable, he found, of being attracted by the magnet; but, when combined with 52 or more, it does not sensibly affect the magnetic needle. Phosphorus, Mr Hatchet found on experiment, had precisely the same effect; rendering iron a powerful and permanent magnet. The three inflammables thus exert a similar action on iron with regard to this property.

Pure iron is extremely infusible. When in contact with burning fuel, it fuses indeed without great difficulty, because it attracts a portion of carbon and oxygen, by which its fusibility is increased. But in covered vessels, it can scarcely be melted in any furnace. This has been accomplished, however. Mr Wedgwood fused soft iron nails in a Hessian crucible in an air furnace, at a heat equal to 154 of his scale. Sir George Mackenzie found, that small pieces of soft iron were completely fused in a covered crucible, when the temperature indicated by one of the pyrometrical pieces of Wedgwood, likewise inclosed, was 158°. In a furnace, in which the temperature was 153, he found that soft iron did not melt. Its melting point must therefore be near 158 of Wedgwood †. Cast iron was found by Mr Wedgwood to melt at 130, but not at 125 ‡.

* Philosophical Transactions, 1804, p. 335.

† Nicholson's Journal, 4to, vol. iv. p. 109.

‡ Philosophical Transactions, vol. lxxii. p. 319.

At a temperature far below that which is necessary for its fusion, iron softens, so that its surface appears as if it were covered with a thick tenacious fluid : this softness extends through the whole mass. In this state the iron is also malleable ; hence it can be beaten into any shape ; and if two pieces thus softened be hammered together, they unite as firmly as if they had been fused into one mass. This property, named *Welding*, belongs to no other metal but platina, and to it in a very inferior degree. It is a very valuable one, as by means of it malleable iron may be worked into various forms, and applied to many purposes, for which it could not otherwise be used. The temperature at which this softening or welding of iron takes place, is a full white heat. Mr Wedgwood has stated it from 90 to 95 of his scale ; but this is undoubtedly by far too high. From some facts related by Sir James Hall, it appears, that at certain temperatures superior to the welding temperature, all iron falls to pieces under the hammer, and that this happens at very different temperatures, in the different varieties of the iron of commerce,—in cast iron at about 15° of Wedgwood, in steel at 30°, in Swedish iron at 50° or 60°, and in Siberian iron at 100° *.

Iron heated under exposure to atmospheric air, suffers oxidizement. If its surface has been polished, ranges of prismatic colours appear upon it, arising probably from this cause : when the temperature is raised to ignition, scales are formed, which may easily be detached ; they are thus obtained in hammering a bar of ignited iron on

* Edinburgh Philosophical Transactions, vol. vi.

the anvil. The sparks struck by flint from steel are similar. When iron wire is introduced at the temperature of full ignition into oxygen gas, it burns with very vivid corruscations, and affords the same oxide, which is fused into globules by the intense heat.

This has been named the Black Oxide of iron. It is brittle, and easily reduced by trituration to a powder, which is of a black colour. It is attracted by the magnet. The metal appears to exist in it in the first degree of oxidizement. The proportion of oxygen was estimated by Lavoisier to amount to 27, with 73 of iron.

By exposing this oxide to a continued heat, it changes its colour, and gradually becomes red, from a higher degree of oxidizement, losing at the same time entirely the property of magnetism. When the oxidizement is complete, the oxide is supposed by Proust to consist of 48 of oxygen, with 52 of iron; and between these two extremes, he supposes, without sufficient reason, that there are no intermediate degrees. By exposing equal parts of the red oxide in powder and of iron-filings to a sufficient heat, the black oxide is produced; and by varying the proportions, various shades of colour may be obtained, denoting various degrees of oxidizement.

These oxides of iron can be obtained likewise by other processes. The black oxide is formed by keeping iron-filings immersed for some time under water, or by passing the vapour of water over ignited iron; and it exists in some of the saline combinations of the metal, from which it may be precipitated by an alkali; a light green precipitate being afforded, which, exposed to a moderate heat in close vessels, becomes black. The red oxide is

obtained, by a similar process, from those saline combinations in which the metal is at a high state of oxidizement. Mr Chenevix has shewn, that iron probably exists in some of its salts in a lower state of oxidizement than the black oxide; a muriate of iron being obtained, by boiling muriatic acid on a larger quantity of metal than it can dissolve, which is colourless; which affords by the alkalis a white precipitate; and which, exposed to the air, forms a green solution, analogous to that which contains the black oxide. The base of this he regards as a white oxide, and, intermediate between this and the black, he supposes a green oxide to exist*. It is probable, from the general theory of metallic oxidation, and from facts with regard to some of the combinations of iron to be immediately stated, that it is susceptible of numerous and probably indefinite degrees of oxidizement.

The oxides of iron cannot be reduced by exposure to heat alone; but when mixed with any carbonaceous matter, and raised to the necessary temperature, the oxygen is abstracted, and the iron returns to the metallic state, combining at the same time with a portion of the carbon.

Iron suffers oxidizement, even at a low temperature, when exposed to a humid atmosphere. This is the rusting of iron. The oxygen appears to be derived from the water, as, when the experiment is performed with moistened iron-filings, a portion of hydrogen gas is evolved, carbonic acid is at the same time absorbed, and perhaps also formed by the oxidizement of the portion of carbon which iron almost always contains. The rust of iron is

* Philosophical Transactions, 1801, p. 225. 226.

a carbonate, or perhaps rather a sub-carbonate of iron. When the water is decomposed by iron, without the access of air, either slowly at a low temperature, or with rapidity at a high temperature, it is a pure oxide, as has already been remarked, that is obtained.

Iron is oxidized and dissolved by the acids, and in these combinations the metal exists, combined with different proportions of oxygen, forming salts therefore with the same acid which have very different properties. The distinctions between these have been attended to only within these few years. These compounds, when neutral, are in general soluble and crystallizable: they have an astringent taste. When the metal is at a high degree of oxidizement, they afford a rich blue precipitate with an alkaline prussiate, and a deep purple one with infusion of galls; two re-agents, which hence form very delicate tests for discovering this metal.

Sulphate of iron is a salt which has long been known, and in use in the arts, under the name of Green Vitriol. It is usually prepared from the decomposition of the native sulphuret of iron, by exposure to air and humidity, oxygen being absorbed, the iron being oxidated, and the sulphur converted into sulphuric acid, with which the oxide of iron combines. The salt is extracted by lixiviation and crystallization, but it is never so pure as when formed by the direct solution of malleable iron in sulphuric acid. The acid, when in its concentrated state, and in the cold, scarcely exerts any action on the metal: if heat be employed, a portion is decomposed, sulphurous acid gas disengaged, and sulphate of iron formed. But if it be diluted with four or five parts of water, the

solution proceeds rapidly : the acid, by its resulting affinity already explained, enables the iron to attract oxygen from the water, hydrogen gas is disengaged with a strong effervescence, and the oxide of iron combines with the sulphuric acid. On filtrating the solution it is of a pale green colour, and, by evaporation, affords crystals, which are of a lively green. This salt, in its crystallized state, consists, according to Mr Kirwan, of 28 parts oxide of iron, 26 of sulphuric acid, 8 of water of composition, and 38 water of crystallization *.

The form of the crystals of the sulphate of iron, is that of a rhomboidal prism. They are soluble in six parts of cold water. Exposed to heat, they suffer the watery fusion, from the temperature enabling the water of crystallization to dissolve the real salt. When this water is dissipated, the salt remains in the state of a greenish-white mass : by increasing the heat, it suffers decomposition, the sulphuric acid is expelled, and this constituted the old process by which this acid was obtained ; at the same time a part of the acid is decomposed : the black oxide of iron, which is the base of the green sulphate, receives part of its oxygen, so as to pass to the state of red sulphate ; some sulphurous acid is of course disengaged ; and this being absorbed by the sulphuric acid, which is the product of the distillation, renders it concrete, and gives it the property of emitting fumes when exposed to the air. This is the substance formerly named Glacial Oil of Vitriol. The red oxide which remains, received the barbarous name of Colcothar of Vitriol : it is probably not entirely freed from sulphuric acid.

* Irish Transactions, vol. vii.

Sulphate of iron, though perfectly transparent, and of a lively green colour when newly crystallized, becomes opaque when exposed to the air : its colour becomes yellowish ; and its surface is at length covered with a powder of this colour. This change is owing not merely to the abstraction of its water of crystallization, but to the absorption of oxygen, in consequence of which the oxide passes to a higher state of oxidizement, and a salt of a different nature is formed. Hence the same change goes on in its watery solution. This is at first of a pale green colour, and perfectly transparent ; but, on exposure to the atmosphere for a very short time, it becomes turbid, and a yellowish precipitate subsides. This is owing to the absorption of oxygen ; and the metal, as it thus becomes more highly oxidized, requiring more acid for its saturation in conformity to the law observed in the relation of metallic oxides to acids, there is not a sufficient quantity of acid present to retain the more perfect oxide in solution ; hence it is precipitated, probably in the state of a sub-sulphate.

Besides the green sulphate of iron, therefore, the base of which is the black oxide, there is a different compound, in which the metal is in a higher state of oxidation. This has been named the Red Sulphate ; and the attention of chemists was more particularly directed towards it by the researches of Proust. It is obtained by leaving the liquor, which remains after the crystallization of the green sulphate, exposed for some time to the atmosphere : the oxide of the salt which is in solution in this liquor continues to absorb oxygen ; and as there is usually an excess of acid in this liquor, it saturates the more perfect oxide as it is

formed. The red sulphate is also produced by heating the solution of the green sulphate with nitric acid, while any nitric oxide gas continues to be disengaged.

The green and the red sulphates of iron have one chemical property by which they can be discriminated, and, if in a state of intermixture, be separated. The green sulphate is not soluble in alcohol, while the red is easily dissolved. The red sulphate is also more abundantly soluble in water, and is retained by it with so much more force, that it cannot be crystallized. When its solution is evaporated, it forms a mass of a yellowish red colour, which is deliquescent. Substances which are capable of abstracting the oxygen of its oxide partially, as sulphurous acid, or sulphuretted hydrogen, bring it back to the state of the green sulphate. Iron-filings digested with it, produce the same change : the metal sharing the oxygen of the perfect oxide, and the whole passing to the state of imperfect oxide. According to the researches of Proust, the oxide, which forms the base of the red sulphate, contains 48 of oxygen combined with 52 of iron*.

The essential difference between these two salts is conspicuous in the phenomena presented by the action of different re-agents upon them. The green sulphate of iron, decomposed by soda or potassa, gives a precipitate of a green colour ; by ammonia, one of the same colour, but deeper : both become black when dried in close vessels. The red sulphate gives, on the other hand, precipitates of a yellow colour, approaching more or less to red, and retaining this redness when dried. The green

* Nicholson's Journal, 4to, vol. i. p. 453.

sulphate gives a white precipitate with prussiate of potassa; the red sulphate, one which is of a rich blue colour: the former is not altered by infusion of galls, the latter produces, with this infusion, a deep purple colour. From the solution of the green sulphate, sulphuretted hydrogen produces no precipitate: from that of the red sulphate, it throws down a dark precipitate.

The tendency of the oxide of iron in the green sulphate to receive a larger proportion of oxygen into the combination is such, that it is difficult to obtain the phenomena above described in perfection. Thus, though tincture of galls does not alter the colour of its solution, yet, in a few moments, exposure to the atmosphere, or the action of the oxygen even of the air contained in the upper part of a phial, is sufficient to communicate a violet tint; and though the prussiates of potassa give a white precipitate, this, from the same cause, very rapidly assumes a bluish appearance. It is even difficult to obtain the sulphate of iron in such a state as not to be coloured by the infusion of galls, or to give a precipitate at least of a light blue, with the prussiate of potassa. As usually crystallized from the solution of iron in diluted sulphuric acid, it is scarcely ever in such a state. It is procured at the *minimum* of oxidizement, by digesting iron-filings with the solution of the common sulphate, by transmitting through the solution sulphuretted hydrogen gas, or, what is the easiest mode, pointed out by Mr Davy, dissolving the artificial sulphuret of iron in diluted sulphuric acid; the sulphuretted hydrogen, which rises through the liquid as the solution proceeds, preserving the metal at the *minimum* of oxidizement. The liquid is boiled for a minute or two,

to disengage any sulphuretted hydrogen : it then gives a perfectly white precipitate with the alkaline prussiate, and is not found to alter the colour of solution of galls *. These differences of colour have usually been ascribed to the formation of different compounds, by the union of these re-agents with the different oxides of iron ; but they are probably as much owing, as Berthollet has suggested, to the circumstance that the iron in these different states of oxidation exerts different forces of affinity to the acid : in the low state of oxidation, its attraction to the acid is too strong to admit of it being precipitated, while in the higher degree of oxidation the affinity is weaker. Hence, if the affinity of the acid be weakened by dilution with water, or by an alkali, the dark colour is produced even with the salt, containing the iron at the *minimum* of oxidation.

Proust supposed, that these sulphates of iron are, in relation to the proportion of oxygen, fixed and determinate ; that there are no compounds of sulphuric acid with oxide of iron, in any intermediate degree of oxidizement between those which constitute the green and the red salts ; and that any salt, or solution, which, from the phenomena it presents with re-agents, appears to be intermediate between these, derives this from an intermixture of the one with the other. The salts or solutions in their usual state, he considers as mixtures of this kind †.

In the solid state, such an intermixture may take place, or the salt at the surface may, from the action of the air, be in one state, while, in the internal part, it is in another.

* Journals of the Royal Institution, vol. i. p. 308.

† Nicholson's Journal, 4to, vol. i. p. 454.

But, in the solution, it can scarcely be supposed that the separate existence of the two salts will be maintained: the one at the lower state of oxidizement will share the excess of oxygen of the other, and one uniform intermediate combination will be established. The oxide in this intermediate state, it may be presumed *a priori*, from the law which we know regulates metallic solutions, will have a relation to the acid different from the mean of the two oxides: it may require, for example, more acid to saturate it, and hold it in solution, than the two salts contained: a precipitate will then be formed. And, accordingly, Berthollet found, that a precipitate was soon formed, on mixing solutions of the salt at the *minimum* and the *maximum* of oxidizement. He adds, what appears to be perfectly just, that a division of the oxygen of the salt in solution, may happen even in the course of its crystallization; and, accordingly, the crystals which are formed in successive crystallizations of sulphate of iron, are of different shades of colour, being pale at first, and becoming more and more green, until the uncrystallizable liquid remains nearly in the state of red sulphate *. Sulphate of iron, therefore, has not fixed proportions of oxygen: there are a minimum and maximum, and, between these insensible gradations, from the one to the other.

The singular property which the green sulphate of iron has of absorbing nitric oxide gas, and the application of this to eudiometry, has already been taken notice of under the history of that gas.

Sulphate of iron is of extensive use in some of the arts,

* Chemical Statics, vol. ii. p. 350.

particularly in the art of dyeing, as forming, by its action on vegetable astringents, an essential ingredient in black dyes, and also in the formation of some pigments, as that of prussiate of iron, the prussian blue of commerce. For these purposes, it requires to be in the state of the red sulphate, or at least to approach to it; but in using it, this is of inferior importance, since even in these combinations the iron quickly passes from a high to a low state of oxidizement, from the action of the atmospheric air.

Sulphurous acid, in its liquid state, or combined with water, acts sensibly on iron-filings: a little hydrogen gas is at first disengaged, which, as Fourcroy and Vauquelin observed, soon ceases: the liquor becomes brown, and ultimately green. This solution, when acids are added to it, effervesces from the extrication of sulphurous acid, and a portion of sulphur is at the same time deposited. It appears, therefore, that in the action of sulphurous acid on iron, part of the acid is decomposed, its oxygen being attracted by the metal, and forming an oxide, with which another portion of the acid combines, while the sulphur of the portion of decomposed acid enters at the same time into this combination. The solution, therefore, is not that of a pure sulphite, but of a sulphuretted sulphite. The pure sulphite may be obtained, by dissolving at once oxide of iron in sulphurous acid: it is soluble in water, insoluble in alkohol, gives a green precipitate with the alkalis, is not coloured by infusion of galls or the prussiates, absorbs oxygen on exposure to the air, so as to pass to the state of sulphate, and yields sulphurous acid from the affusion of other acids. The sulphuretted sulphite

is soluble in alkohol : it is permanent in the air, and, when acted on by acids, gives a precipitate of sulphur *.

Nitric acid acts on iron very forcibly, is decomposed, and a large quantity of nitric and nitrous oxide gases, mingled with nitrous acid vapour, are disengaged ; the iron passing at the same time to a high state of oxidizement, and retaining a portion of the acid in combination, but not sufficient to form a soluble compound. When the nitric acid has been pretty largely diluted with water, the action is more moderate, and the iron is slowly dissolved. The solution is of a colour varying from yellowish brown to green. It cannot be evaporated so as to afford crystals, as, when heated, the temperature facilitates the farther decomposition of the acid, and the iron, passing to a higher state of oxidizement, is in part precipitated in the state of a sub-nitrate. On exposing it to the air, a similar change is effected, oxygen being absorbed. Even in any state, the nitrate of iron does not appear to be obtained, with the metal, at the *minimum* of oxidizement ; as from its solution, prepared with a diluted acid and in the cold, the alkalis throw down a yellowish or brown precipitate. Nitrate of iron is decomposed by heat, and the metal remains in a highly oxidized state, in the form of a powder of a bright red colour.

Iron is dissolved with facility by muriatic acid, even when the acid has been diluted with three or four parts of water : the iron receives the oxygen necessary to its combination with the acid from the water ; and hence the solution is accompanied with the disengagement of hydro-

* Fourcroy's System, vol. vi. p. 273.

gen. The iron in this combination may exist either at the *minimum* or the *maximum* of oxidizement, according to the manner in which it has been effected.

It exists nearly in the former state, when iron-filings are dissolved in diluted muriatic acid, and the atmospheric air is excluded from the solution ; or it is perhaps obtained still less oxidized, by the solution of the artificial sulphuret of iron in the acid, applying to the solution a very moderate heat, so as to expel any sulphuretted hydrogen gas that might be retained. The solution of the salt in this state is of a yellowish-green colour, and by evaporation affords crystals, the colour of which is a pale green. They are abundantly soluble in water : when the solution is exposed to the air, oxygen is absorbed, the iron passes to a higher state of oxidizement, and is in part precipitated in the state of a sub-muriate. The green muriate of iron, as the salt at the low degree of oxidizement may be named, is acted on by re-agents nearly in the same manner as the green sulphate. It is decomposed by the alkalis, giving a green precipitate : its colour is not altered by infusion of galls ; and with the alkaline prussiates it forms the white prussiate of iron. Its solution absorbs nitric oxide gas with even more facility than the solution of the green sulphate, and this impregnated solution absorbs oxygen, and suffers changes similar to those of the sulphate, which have been already described.

The muriate in which the metal is at a higher state of oxidizement, may be formed by dissolving the oxide in muriatic acid : a solution is thus obtained of a yellow colour, more or less deep, according to its state of concentration. It does not crystallize, but by evaporation

affords a yellow deliquescent mass. It is soluble in alcohol, the solution being of a lively yellow colour, and forming a tincture which is used in medicine. Decomposed by heat, or by concentrated sulphuric acid, it gives out muriatic and oxymuriatic acids, the latter being formed by a portion of the former receiving oxygen from the metallic oxide. By continuing the application of heat, a muriate of iron is sublimed. Decomposed by the alkalis, it gives a yellowish-brown precipitate.

A ternary combination of oxide of iron with muriatic acid and ammonia, is formed by mixing oxide of iron and muriate of ammonia, and applying heat to the mixture in a matrass: a yellow matter, consisting of this combination, is sublimed. It is used in the practice of medicine.

Carbonic acid is capable of combining with oxide of iron. When water, impregnated with this acid, is kept on iron-filings in a closed phial, it acquires the styptic taste of the salts of iron, part of the iron being oxidized probably by the oxygen held in solution by the water, and this oxide combining with the acid. The common rust of iron consists of the oxide of the metal, in combination with carbonic acid, either absorbed from the atmosphere, or formed from the oxygenizement of the carbon which iron always contains. It is scarcely disengaged by the affusion of an acid, and does not appear to be in sufficient proportion to neutralize the oxide. A similar compound is obtained by decomposing sulphate of iron by an alkaline carbonate. The precipitate of oxide in combination with the carbonic acid, which is formed when the solutions of the two salts are mingled together, is of a deep green colour; but, in drying, it assumes the

usual colour of the rust of iron. Carbonate of iron frequently occurs in mineral waters, being held in a state of perfect solution by an excess of carbonic acid. This escapes when the water is exposed to the atmosphere; the iron at the same time becomes more highly oxidized; from both causes it becomes insoluble, and precipitates in the state probably of a sub-carbonate. This forms the yellow sediment so common in chalybeate springs.

The action of phosphoric acid on iron is not considerable. Its combination with the metal oxidized may be obtained indirectly, by mixing solutions of sulphate of iron, and phosphate of soda; a precipitate of phosphate of iron is formed, of a white colour, and insoluble in water. It is capable of being fused by a violent heat into a globule having metallic brilliancy. Heated with charcoal, the acid is reduced, and the phosphuret of iron formed.

Fluoric acid combined with water dissolves iron, the solution being accompanied with the disengagement of hydrogen gas from the decomposition of the water. The solution does not crystallize; but, by concentration, assumes a gelatinous consistence. It is decomposed by heat, which expels the fluoric acid.

The action of boracic acid on iron is so weak, that scarcely any sensible portion of the metal is dissolved. The acid, in combination with oxide of iron, is obtained, by adding a solution of borate of soda to a solution of sulphate of iron. The compound is insoluble.

An acid derived from the animal kingdom, the Prussic Acid, is distinguished by the strength of its affinity for iron, in consequence of which it affords one of the reagents of most delicacy, by which this metal can be de-

tected in any of its combinations. When the iron is at the minimum of oxidizement, the compound is white; but when more highly oxidized, it is of a rich blue colour. The pigment, known by the name of Prussian Blue, has for its basis this compound. These combinations are to be afterwards noticed.

Another acid, derived from the vegetable kingdom, Gallic Acid, affords also a re-agent of great delicacy as a test of the presence of iron. The compound it forms with the iron above the minimum of oxidizement, is of a deep purple colour, so as when not much diluted to appear black. The more full account of this combination, belongs to the chemical history of this acid.

The alkalis do not act on iron in its metallic state; and they scarcely dissolve even any perceptible quantity of its oxides. The perfect oxide of iron is partially decomposed by ammonia, a portion of its oxygen being abstracted by the hydrogen of the alkali, so that it passes from the red colour to a brown, or even a black. Fourcroy has affirmed, that the same change even is effected by the action of the fixed alkalis on the red oxide, when assisted by heat *. The alkalis appear also to form ternary or quaternary combinations with the oxides of iron and several of the acids. Thus, carbonate of potassa or of ammonia, added to a solution of nitrate of iron, throws down a yellowish-red precipitate, which is re-dissolved when an excess of the carbonate is added, owing to such a combination being established.

The oxides of iron, fused with the earths, produce co-

* System of Chemistry, vol. vi. p. 298.

coloured enamels ; and, in the humid way, they contribute to their connection and induration, by an operation not well understood. Hence, they enter into the composition of the best cements.

Iron has a strong affinity for Carbon, as is evident from the iron combining with a portion in the process of its reduction. The metal in this state, however, also contains a portion of oxygen. The combination of iron with carbon alone exists in nature, forming the mineral production known by the name of Black Lead, and described by mineralogists under the names of Plumbago and Graphite. Produced by artificial arrangement, it forms Steel.

It has been stated, under the history of carbon, that Scheele had proved that plumbago contains carbon, since, by slow combustion, or by heating it with nitre, it affords carbonic acid. He observed also, that it requires more nitre for its consumption than the same weight of charcoal does : and from this, Guyton, who confirmed the fact, and added the observation, that it affords a larger quantity of carbonic acid, inferred, that plumbago approaches nearer to the state of pure carbon than charcoal does, or is that base in its first degree of oxidation.

Plumbago, however, cannot be regarded merely as an oxide of carbon, for iron is always contained in it, and appears to be essential to its composition. Scheele observed, that a residuum of iron was always obtained in deflagrating it with nitre, or by exposing it to a high temperature alone until it ceased to lose weight, the quantity amounting to about 10 parts in 100. Pelletier, who likewise analysed a number of specimens of plumbago, always detected iron in it. The plumbago from Cumberland ap-

peared, from his experiments, to contain the smallest proportion *. A variety, analysed by Vauquelin, gave a small portion only of iron, not more than 2 in 100, while it afforded of silex 38 parts, of argil 37, and of carbonaceous matter only 23 †. This, however, must have been extremely impure. Mr Davy, from his late researches, has concluded, that carbon, or the element of diamond and of charcoal, exists in plumbago in its purest form, being only combined with a portion of iron.

Plumbago, though consumed by a continued heat, burns very slowly, and with scarcely any flame: the residuum consists of the iron and impurities which may have been mixed with it. When mixed with a large quantity of nitre, and thrown into an ignited crucible, it is rapidly oxidized. Ten parts of nitre are requisite to burn one part of plumbago, while five parts are sufficient for the deflagration of one part of charcoal. Scheele remarked, that this substance, when digested and boiled in the acids, was not sensibly dissolved, farther than that a small portion of iron was extracted. This has been confirmed by Pelletier, in his experiments upon it ‡. It is singular, that it is not in the least altered by repeatedly distilling nitric acid from it. Sulphuric acid, however, distilled from it, is partially decomposed and converted into sulphurous acid, as Pelletier found, no doubt from its much greater fixity, whence the temperature can be raised higher. From the same cause, arsénic acid and phosphoric acid,

* *Mémoires de Chimie*, tom. i. p. 184.

† *Journal des Mines*, No. 12.

‡ *Mémoires de Chimie*, tom. i. p. 146.

when heated with it, are de-oxidized. The fixed alkalis, exposed to a strong heat with plumbago, were observed by Scheele to afford inflammable air; the alkali at the same time losing its causticity, and effervescing with acids. This also was observed by Pelletier, who obtained carbonic acid by this effervescence. The water present had probably been decomposed, whence the origin of the carbonic acid and the hydrogen gas. Heated with a number of the metallic oxides, it reduces them to the metallic state. Pelletier could not succeed in combining it with any of the metals.

Native carburet of iron is applied to several uses. It forms the best kind of crayons; slips of it being cut and fixed in a groove, in a slip or cylinder of wood. It is employed in the construction of crucibles, and even of furnaces; its powder being mixed with clay, baked, and hardened by a strong heat. It communicates tenacity to the clay, which renders the composition much less liable to be rent; and being enveloped in the clay, while its combustibility is at the same time so inconsiderable, it scarcely suffers any change in the most intense fire. It is sometimes added to the earths, of which earthen ware is prepared. When rubbed on the surface of iron which is to be exposed to humidity, it in a great measure preserves it from rusting. It is likewise used to give a lustre to small lead shot. And by its softness and lubricity, it is adapted to diminish the friction of machinery, and facilitate the motion of one surface over another.

Pelletier observed, that in the fusion of some ores of iron on the large scale, a substance separates, and floats on the surface, which resembles plumbago very closely

in its scaly texture, its lustre, and its softness. It had also the same chemical qualities, burning with difficulty, not being affected by the acids, and producing an inflammable air when heated with a fixed alkali. It is therefore to be regarded as a carburet of iron, either previously existing in the iron ore, and separated during the fusion, or formed by a combination of carbon with a portion of iron. A similar substance, as Bergman announced, is precipitated during the solution of some kinds of cast iron in diluted sulphuric acid.

Iron combined with a much smaller proportion of carbon forms Steel. Different methods are followed to form this combination : the product varies according to these, and also from the introduction of other substances into the combination.

The general method of forming steel, is by the process of cementation. A furnace is constructed of a conical form, in which are two large cases or troughs of fire-brick, capable of holding some tons of iron. Beneath these is a long grate, on which the fuel is placed : on the bottom of the case is laid a layer of charcoal dust or powder : over this a layer of bars of malleable iron ; over this again, a layer of charcoal powder ; and the series of alternate layers of charcoal and iron is thus raised to a considerable height : the whole is covered with clay to exclude the air, and flues are carried through the pile from the furnace, so as to communicate the heat more completely and equally. The fire is kept up for eight or ten days. The progress of the cementation is discovered by withdrawing a bar from an aperture in the side : if the conversion of the iron into steel appear to

be complete, the fire is extinguished : the whole is left to cool for six or eight days longer, and is then removed.

The iron prepared in this manner, is named Blistered Steel, from the blisters which appear on its surface. To render it more perfect, it is subjected to the action of the hammer, in nearly the same manner as in the manufacture of forged iron : it is beat very thin, and is thus rendered more firm in its texture, and more convenient in its form. Another mode of improving its quality, is to expose the bars of blistered steel to heat in a furnace sufficient to soften them, when they are welded together, doubled and drawn out, and sometimes welded again, forming what is named Shear Steel. Steel is rendered still more perfect, by fusing the bars of common blistered steel with a little charcoal powder, and a flux of pounded glass in a large crucible, placed in a wind furnace, the steel being rendered harder or softer as more or less of the flux is employed. When the fusion is complete, it is cast into small bars or ingots, and is named Ingot Steel. Lastly, even this steel is for some purposes still farther subjected to the action of the hammer, by which its texture is rendered more compact ; and this gives steel in its most valuable form *.

Steel is generally prepared from malleable iron. It can also, however, be formed from some kinds of crude iron. Crude differs from malleable iron in containing oxygen and carbon. If the oxygen be abstracted without the carbon, or if, during the operation, a new portion of carbon be brought into combination, steel will be formed. Some

* Manchester Memoirs, vol. v.

varieties of crude iron have accordingly been used for this purpose,—the grey crude iron in particular: the black crude iron furnishes a steel that is too brittle. The crude iron from certain ores, as the sparry iron ore, is well adapted to this conversion. The steel thus obtained is named Natural Steel; but it is inferior to that obtained by cementation.

From the mode in which steel is formed from iron, it must appear probable *a priori*, that the change is owing to the combination of carbon with iron. The truth of this conclusion was first established by Bergman by a series of very excellent experiments. He found, that by dissolving malleable iron in diluted sulphuric acid, a larger quantity of hydrogen gas was evolved, from the solution of a given weight of the metal, than from the solution of the same weight of steel in the same acid; about 50 ounce measures of hydrogen being obtained from the solution of the one, when, from that of the other, the quantity amounted only to 48 ounce measures. This shewed that less water was decomposed by the one than by the other,—a difference owing to the steel containing carbon, which did not contribute to this decomposition, whence a given weight of it contained less iron, by which only the decomposition was effected. This carbon was discovered by its separation, during the solution of the steel, in the form of a black shining powder, which Bergman found to be perfectly analogous to plumbago or native carburet of iron. From 200 parts treated in this manner, Bergman obtained one part of plumbago*.

The experiments of Bergman were confirmed by those

* Opuscula Physica, vol. iii.

of Monge, Vandermonde, and Berthollet : and these chemists were farther enabled, from the principles of the antiphlogistic theory, to give with more precision the theory of the conversion of iron into steel : they shewed also, that in this conversion there is an augmentation of weight ; and they observed, that the quantity of carbon combined with the iron in steel, cannot be estimated correctly from the quantity of plumbago deposited during the solution of the steel, as part of it must be dissolved by the hydrogen disengaged during the solution *.

The quantity of carbon combined with iron to constitute steel is different in the different varieties. In general, an increase of weight is gained by the iron, amounting to from $\frac{1}{80}$ th to $\frac{1}{40}$ th of the original weight of the iron. The more carbon is introduced, the steel is more brittle : and so much may be introduced, that the most valuable qualities of the steel are entirely lost. The quantity of carbon is greater, not only according to the proportion of charcoal used in the cementation, but also as the temperature has been more highly raised. The presence of carbon in steel, is shewn by a very simple experiment, that of letting fall a drop of nitric acid on polished steel, which leaves a stain, by dissolving the iron of the surface, and leaving the carburet of iron or plumbago.

The combination of iron with carbon, so as to form steel, is attained, not only by the preceding processes, but likewise by fusing bar iron with charcoal in a crucible exposed to an intense fire ; different varieties of steel being formed, according to the proportions. From a pro-

* Mémoires de l' Acad. des Sciences, 1786, p. 132.

cess for forming steel given by Clouet, it has been inferred, that at a high temperature, iron is capable of decomposing carbonic acid, and of attracting its carbon. The process consists in exposing to a strong heat in a crucible, iron in fragments, with one-third of its weight of carbonate of lime, and the same proportion of argil. By fusion, steel is formed *. Mr Mushet, in repeating this process †, however, found the product to be different in its properties from steel, though at the same time the iron was altered in its qualities : it was harder, but possessed of less tenacity and elasticity. Sir George Mackenzie has remarked, that the substance obtained in this way from some kinds of iron, is somewhat analogous to steel, particularly in becoming very hard when heated red hot and plunged into cold water ; and has supposed, that these properties may be acquired from some combination of the earths with iron,—a conjecture confirmed by the fact, that steel generally contains a portion of silex ‡.

Guyton has observed, that it is probably not mere charcoal that enters into the composition of steel, but carbon in its pure state ; and that from this the great hardness of steel may be derived. This conjecture was confirmed by a very satisfactory experiment,—that of converting a piece of malleable iron made into a crucible into steel, by putting into it a small diamond, filling up the remaining cavity with iron-filings, and exposing the whole in a crucible to a strong heat, urged by bellows. At the end of

* Nicholson's Journal, 4to, vol. iii. p. 131.

† Philosophical Magazine, vol. xii. p. 27. 97.

‡ Nicholson's Journal, 4to, vol. iv. p. 109.

an hour, the apparatus having been removed from the fire, the crucible, iron-filings, and diamond, were found in one mass rounded, and of the nature of steel*. This experiment was performed with a result still more satisfactory by Sir George Mackenzie, the product being proved to have all the characteristic properties of steel †.

Bergman had observed, in his analysis of steel, that some varieties of it contained portions of silex and manganese; and those ores of iron which contain manganese have been believed to be best adapted to the production of steel. Vauquelin, repeating the analysis of steel, with the improved methods which his skill in such researches suggested, did not discover manganese, but silex and phosphorus. The following table gives the results of the analysis of four different specimens of steel ‡.

	No. 1.	No. 2.	No. 3.	No. 4.
Carbon,	0.00789	0.00683	0.00789	0.00631
Silex,	0.00315	0.00273	0.00315	0.00252
Phosphorus,	0.00345	0.00827	0.00791	0.01520
Iron,	0.98551	0.98217	0.98105	0.97597
	1.00000	1.00000	1.00000	1.00000

Steel is of a grey colour: its fracture is granular: it is brilliant, and is susceptible of a very high polish, which, from its hardness, it preserves: it is more fusible than iron, and is capable of being fused and cast: it is both ductile

* Nicholson's Journal, 4to, vol. iii. p. 358.

† Ibid. vol. iv. p. 105. ‡ Ibid. vol. i. p. 252.

and malleable, and, when beat at a high temperature, it can be beat into thinner plates than iron can. Cast steel is incapable of welding. When hammered, its specific gravity becomes greater, and its ductility and elasticity are increased. The specific gravity of bar steel is about 7.3 or 7.4; that of the same steel hammered 7.7.

But the property which peculiarly characterizes steel, and which gives it its high value, is that of becoming extremely hard, by being hastily plunged into cold water, when it is heated to redness. The hardness thus acquired, is greater as the steel has been hotter and the water colder. The effect produced by this sudden reduction of temperature is mechanical. The particles being suddenly approximated and united, that arrangement which would rise from their slow approximation, and give rise to softness and ductility, is prevented. The proof of this is, that steel, hardened in this manner, may have its softness and ductility restored to it, by again heating it, and allowing it to cool slowly.

The harder steel is, it is also the more brittle; and hence, for the various uses to which it is applied, it must be made of different degrees of hardness; for although an excess of this quality alone might not be hurtful, yet the correspondent brittleness would, for certain purposes, render it useless. This gives rise to what is termed Tempering of Steel, which is nothing but the art of giving it any requisite degree of hardness.

The method of effecting this formerly practised, was first to harden the steel, by plunging it when hot into cold water. It was then reduced to the desired temper, by heating it slowly, and allowing it to cool gradually

The colours which appear on the surface of the heated metal, are found to indicate certain degrees of hardness, which will be possessed by the metal when cold: the straw colour, for instance, indicating the proper hardness for cutting instruments; the blue, the temper for springs, or any instrument which requires to be elastic, and so on of several others.

Within these few years, a much easier method of giving the requisite temper has been practised. The pieces of steel are covered with oil or tallow, or put into a vessel containing either of these ingredients, and heated over a moderate fire. The appearance of the smoke from the oil or tallow, indicates the degree of heat. If the smoke just appear, the temper corresponds with that indicated by the straw colour when the metal is heated alone. If so much heat is applied, that a black smoke arises, this points out a greater hardness; and thus proceeding till the vapour catch flame. By this method, a number of pieces may be done at once, with comparatively little trouble, and the heat is also more equally applied*.

Steel possesses a degree of hardness superior to that of any metal: it cuts glass, and gives copious sparks when struck with a flint. It is also possessed of the highest elasticity, and is capable of taking a very fine polish. The combination of these properties adapts it to many uses, and gives it its high value.

Iron combines with Sulphur with great facility, when the temperature is raised so as to melt the sulphur. Thus, if a roll of sulphur be applied to a bar of iron red hot,

* Philosophical Magazine, vol. ii. p. 97.

the iron and sulphur combine together, and, as the compound is very fusible, the iron is thus melted. Or the combination is easily made, by exposing to a moderate heat a mixture of iron-filings and sulphur. This combination is accompanied with a brilliant illumination, similar to that which, it has already been remarked, takes place in the combination of copper and sulphur.

The sulphuret of iron, artificially formed, is generally produced with proportions different from those which exist in the natural sulphuret. In the latter, they are nearly equal parts, or, according to Proust, are as 47 of sulphur to 53 of iron; and according to the analyses of pyrites by Mr Hatchet, the sulphur even exceeds the iron; the proportions, on an average, being 53 of sulphur and 47 of iron. In the artificial sulphuret, the sulphur is in much smaller proportion, not exceeding, according to Proust, 37.5 in 100 parts of the compound; nor is it easy to bring a larger proportion into combination, by the direct fusion of iron and sulphur; but it can be done by again fusing the sulphuret, obtained by the usual process, with an additional proportion of sulphur. A compound is then formed analogous to the natural pyrites.

Proust supposed that sulphur and iron combine only in these two proportions, which form the *minimum* and *maximum* *. By varying the proportions, however, numerous intermediate combinations may be formed, and even less sulphur, as 26 in 100 parts, may exist in the compound. Mr Hatchet has shewn, that when the proportion of sulphur does not exceed 37 in 100 of the

* Nicholson's Journal, 8vo, vol. i, p. 269.

compound, it is magnetic; that when the proportion amounts to 45, it is capable of being attracted by the magnet; but that when equal to 53, the magnetic power is entirely destroyed *.

The properties of sulphuret of iron vary according to the proportions. When the sulphur is in smaller proportion, the compound has a grey colour intermixed with purple and yellow, with a degree of metallic lustre; and when it has been formed by fusion, a crystalline texture. It is brittle; and gives a black powder. It is also very fusible. When the proportion of sulphur is larger, the compound approaches more in its appearance to the natural pyrites: its colour is yellow; and its lustre is greater. Exposed to heat in close vessels, a considerable part of the sulphur may be volatilized.

The first of these sulphurets, when moistened and exposed to the air, is decomposed, oxygen being absorbed, and sulphate of iron formed. When diluted muriatic or sulphuric acid is poured upon it, there is an immediate disengagement of sulphuretted hydrogen; the acid enabling the iron to decompose the water; and the hydrogen evolved, in consequence of this decomposition, dissolving a portion of the sulphur. The sulphuret, which contains an excess of sulphur, does not exhibit the same phenomena, either on exposure to humidity, or to the action of diluted acids; the affinity of the sulphur to the iron being probably so far aided by its quantity, as to maintain the combination, or resist the oxidation of the metal.

Iron and sulphur even act on each other, at a low tem-

* Philosophical Transactions, 1804, p. 336.

perature, when moistened. If a mixture of iron-filings and sulphur in this state, be exposed to the atmosphere, oxygen is quickly absorbed,—an absorption which would not happen from the action either of the sulphur or iron alone. If the air be excluded, the water is decomposed by the mutual action of the iron and sulphur.

The alkaline sulphurets appear to be capable of combining by fusion with iron; and their aqueous solutions, in which the sulphur exists in the state of a sulphuretted hydro-sulphuret, dissolve a portion of iron-filings, when boiled on them. From this solution, acids throw down a hydro-sulphuretted oxide of iron. Sulphuretted hydrogen, and the hydro-sulphurets, cause the deposition of a black precipitate from the solutions of iron.

Iron combines with Phosphorus, by exposing to heat in a crucible equal parts of iron-filings and concrete phosphoric acid, with a third of their weight of charcoal powder; or even by projecting pieces of phosphorus on iron at a red heat. The phosphuret of iron is of a white colour, has a granular fracture, is brittle and fusible. Bergman having obtained this substance from that variety of iron named Cold Short Iron, by solution in diluted sulphuric acid, considered it as a peculiar metal, to which he gave the name of Siderite. Scheele and Klaproth discovered its real nature. It has been considered as the cause of the cold short property of iron.

Iron is capable of combining with a number of the metals, but there are only a few of these alloys applied to any useful purpose. Its alloy with gold is very hard, and at the same time has considerable ductility and malleability: its colour is a dull grey, or, if the proportion of

iron much exceed that of the gold, white. From the affinity between the two metals, gold can even be used as a solder to unite pieces of steel. Iron and silver may be combined by fusion. According to an experiment on this combination by Guyton, they have a tendency to separate when kept in fusion, and arrange themselves according to their specific gravities. Each of the metals, however, retains a portion of the other: the silver becomes sensibly magnetic, and the iron is altered in its properties; it becomes harder and more brittle, and when dissolved in nitric acid gives a precipitate on the addition of muriatic acid. Though platina in its native state is alloyed with iron, it is difficult or scarcely practicable to combine them together, owing no doubt to their great infusibility. Lewis accordingly found, that cast iron might be combined by fusion with platina: it produced an alloy extremely hard. With quicksilver, iron can scarcely be combined, the iron not being in the least changed, when the mercury is applied to its surface. The combination, however, can be effected by some indirect methods. Thus, by rubbing iron-filings with twice its weight of silver, and adding rather more of quicksilver than the weight of the iron, continuing the trituration with the addition of a little water for an hour or two, an amalgam is formed, in which the combination appears to be progressive for some time, as it continues to swell and split *. Mr Aikin likewise succeeded in forming an amalgam of iron, by uniting an amalgam of zinc and mercury with iron-filings, and adding to this muriate of

* Crell's Chemical Journal, vol. ii. p. 103.

iron : the zinc attracts the oxygen and muriatic acid from the iron, and the quicksilver and iron unite *. The alloy of iron with copper is not very perfect : it is of a grey colour, brittle, and not very fusible. It is applied to no use.

The qualities of which iron in its various forms is possessed, render it the most useful of all the metals. In hardness, no metal is equal to steel, and no substance, in combination with this quality, possesses such a degree of tenacity ; hence its adaptation to the fabrication of cutting instruments. It is equally superior in elasticity,—a quality from which it is the spring of motion in more delicate machinery. The toughness of malleable iron, adapts it to purposes where strength is required ; while the singular combination of its infusibility, with its property of softening by heat so as to admit of a close assimilation and union of its parts, renders it at once capable of being worked, and of bearing the most intense heat. Surveying the applications of this metal, in the fabrication of tools and instruments, in the construction of time-pieces, in the magnetic needle, and in the numerous other uses to which it is applied, it must soon be perceived, that it is superior to all the metals in real value,—a value well displayed in the superiority it confers on civilized nations, and in the slow progress of the arts of life in barbarous tribes unacquainted with its use.

* Philosophical Magazine, vol. xiii. p. 406.

CHAP. XI.

LEAD.

THIS metal, of a light blue colour, has considerable lustre, which is very quickly lost, however, on exposure to the air. It is the softest and least elastic of all the solid metals: it has very little ductility, or it cannot be drawn into very fine wire; and a wire of it, one-tenth of an inch in diameter, cannot support more than 30 lbs. without breaking. It is more malleable, and may even be beat into thin leaves. Its specific gravity is 11.352. Its taste and smell, when it is rubbed, are peculiar and rather disagreeable; and it is one of the metals which proves highly noxious to animal life. It occurs in nature, mineralized by sulphur, by carbonic, sulphuric, phosphoric, arsenic, molybdic, and chromic acids.

The sulphuret, or galena as it is named, is the ore which is generally wrought, and from which nearly all the lead of commerce is procured. The extraction of the metal is very easy. The ore pounded, and freed from the admixture of any stony matter by washing, is fused in a furnace, with the addition of lime, which combines with the sulphur of the sulphuret; the lead is melted, and run out by an aperture towards the bottom of the furnace. When the native salts of lead are found with the galena, so as to render it of importance to work them, they are selected

until a sufficient quantity be obtained : they are then roasted to expel the volatile matter, and are afterwards fused in contact with the fuel, with an addition of lime. The lead obtained from galena, sometimes contains so much silver, as to be subjected to an additional process to separate the silver. The lead is oxidized on the hearth of the refining furnace ; a current of air being directed on its surface when in fusion, by bellows, by which the lead is more quickly oxidized, and the oxide is semi-vitrified, forming what is named Litharge ; by the blast of air, this is driven towards an aperture in the furnace, where it is allowed to flow out : towards the end of the operation, the silver remains with a small portion of lead, from which it is freed by cupellation ; and the oxide of lead is either applied to the purposes for which it is used, or is reduced*.

Lead melts at a temperature a little inferior to ignition, equal, according to Sir Isaac Newton's calculation, to about 540 of Fahrenheit. Dr Irvine, by the mercurial thermometer, found its fusing point to be 594 †. By the process formerly described for obtaining metallic crystallizations, it can be obtained in the form of a tetrahedral pyramid, single, or often united by the base. At a very high heat it is volatilized.

Lead is very susceptible of oxidizement. When first fused, its surface is perfectly bright ; but in a very short time, if the air is not excluded, it becomes dull, is covered with a thin film, which increases in thickness, forming

* An ample account of this process is given in Aikin's Chemical Dictionary, article Silver.

† Chemical Essays, p. 35.

at length a powder, which is named the dross of lead. If this be withdrawn, the same phenomena are again presented, and thus the whole of the lead may be converted into this powder, which is of a grey colour. It is the metal in the first degree of oxidizement; but, as obtained by this process, it has always diffused through it particles of reduced lead. By exposing it to a higher heat, with the access of air, it acquires a lively yellow colour, forming the pigment named *Massicot*, in which the metal is to be considered as more highly oxidized. Proust has, without any reason, supposed that the grey oxide is a mixture of this yellow oxide with metallic lead. By continuing the application of the heat, and raising it a little, and causing the flame to play upon the surface, while the powder is at the same time constantly stirred, the yellow colour changes to a red, which at length, when the process is carried on in the large way, and with particular management, becomes very bright: this forms the paint known by the name of *Minium*, or Red Lead, and which is the metal in a high state of oxidizement. By a particular management of the heat during the oxidizement of lead, applying it quickly with a current of air blown over the surface of the metal, the oxide is semi-vitrified, forming the soft flaky substance named *Litharge*; a product, however, which is generally obtained in the process of extracting silver from lead. By a stronger heat, this may be completely vitrified, when it forms the Glass of Lead.

It is extremely probable, as Berthollet has remarked *,

* Chemical Statics, vol. ii. p. 317.

that as there are no determinate circumstances in the oxidizement, no change to interrupt its progression, it will be indefinite. By analysis, however, the composition of the oxides, obtained at certain stages of the process, and defined by certain properties, may be ascertained. The degree of oxidizement in the grey oxide has not been fixed. Proust supposed, that the yellow oxide, in the state in which it is obtained, by decomposing nitrate of lead by potassa, consists of 91 of lead, with 9 of oxygen. Dr Thomson, in a memoir on the oxides of lead *, states, that the yellow oxide, obtained by decomposing the nitrate of lead by carbonate of potassa, and further decomposing the precipitate of carbonate of lead by heat, consists of 89.7 of lead, and 10.3 of oxygen. The red oxide, Dr Thomson regards as composed of 88 of lead, with 12 of oxygen. Litharge, he found to contain a little carbonic acid, about 4 parts in 100, united with the yellow oxide. The existence of another oxide of lead has been supposed, named the Brown Oxide, containing, according to Proust, 21 of oxygen in 100. Scheele formed the substance to which this name has been given, by digesting diluted nitric acid on the red oxide: the greater part of this is dissolved, but a portion remains undissolved, which assumes a brown colour. A similar product is obtained, as Vauquelin observed, by transmitting oxymuriatic acid gas over the red oxide suspended in water, and precipitating the solution thus obtained by potassa. From the nature of either of these processes, there is every reason to believe that the substance formed must be a sub-salt. It

* Nicholson's Journal, 8vo, vol. viii. p. 280.

is of a deep brown colour : when decomposed by heat, it affords very pure oxygen, and melts into a glass : it also gives out oxygen, when acted on by sulphuric acid : it is not soluble in nitric, but dissolves in nitrous acid : with muriatic acid, it forms oxymuriatic acid gas : it also decomposes ammonia,—properties which shew that it contains much oxygen *.

The oxides of lead have a considerable specific gravity: they are tasteless and insoluble in water : they are fused by heat ; and act as very powerful fluxes on earthy matters. The red oxide is partially decomposed by heat, giving out oxygen, and passing into the yellow oxide, or, if the heat be strong, being completely vitrified. They are all easily reduced by exposure to heat with carbonaceous matter, or by heating them in hydrogen gas.

Lead does not decompose water at any temperature, so as to produce any sensible disengagement of hydrogen gas. But when kept immersed in water, it becomes at length covered with a white efflorescence or crust, produced probably by the action of the oxygen, which water holds loosely dissolved.

The greater number of the acids either act on lead, or, at least, they combine with its oxides. Its saline combinations are very generally distinguished by a sweet styp-tic taste. These combinations can scarcely be formed with the metal at the *maximum* of oxidizement ; the red oxide generally giving out part of its oxygen, when acted on by acids. They appear to be formed of an oxide analogous to the yellow.

* Fourcroy's System, vol. vi. p. 122.

Sulphuric acid scarcely acts on lead in the cold ; but when made to boil on it, sulphurous acid is disengaged, and the metal, being oxidated, combines with part of the sulphuric acid, and forms a white mass, in which there is a considerable excess of acid. This is sparingly soluble in water : a small portion, however, is dissolved from the excess of acid ; and, on evaporation of the solution, needle-like crystals are obtained. The neutral sulphate is best obtained by decomposing any of the soluble salts of lead, by sulphuric acid, or rather by an alkaline sulphate. It is precipitated in a dense white powder, which is almost insoluble, or, at least, requires above 1000 parts of water for its solution. According to Kirwan's estimate, it consists of 75 of oxide, (composed of 71 of lead and 4 of oxygen), 23.37 of acid, and 1.63 of water.

Sulphurous acid does not act on lead ; but Fourcroy and Vauquelin, in their researches on the combinations of this acid, found, that by placing the red oxide of lead in contact with this acid, it became white, and a saline mass was formed, containing both sulphate and sulphite of lead. The latter, they also found, can be obtained pure, by adding the white oxide obtained from the nitrate, to sulphurous acid. It is in the form of a white powder, insoluble in water *. Both it and the sulphate are partially decomposed by heat, and, when heated on charcoal by the blow-pipe, are reduced.

Nitric acid, a little diluted, acts readily on lead ; nitric oxide gas is disengaged, and the metal oxidized. This oxide combines with the acid, and forms a soluble salt :

* Fourcroy's System, vol. vi. p. 115.

the solution by evaporation deposits crystals, which, when formed slowly, appear to be triedral, or hexaedral pyramids: they are white, with a degree of adamantine lustre, and are semi-transparent. They are not, like many of the metallic nitrates, decomposed by water, but are dissolved. They deflagrate with decrepitation when thrown on burning fuel, and are decomposed when exposed to heat alone, the acid being partly expelled, partly decomposed, and the oxide being vitrified. A white precipitate is thrown down from it by the alkalis. It consists, according to Dr Thomson, of 66 of oxide, and 34 of acid and water *.

The oxide in this salt appears to be the yellow oxide; and this oxide, added to the acid, is at once dissolved in it. When nitric acid is poured on the red oxide, the oxide is not dissolved, but the degree of its oxidizement is changed: it becomes, as Proust has observed †, at first white, and a portion of it suffers solution, but another part, about one-seventh of it, acquires a brown colour, and remains insoluble. This is probably a sub-nitrate, containing the metal at the maximum of oxidizement, while the salt in solution is similar to that formed by the direct solution of lead in nitric acid, or perhaps rather more highly oxidized. A solution in which, according to Proust, the metal is in a lower state of oxidizement than the yellow oxide, may be obtained, by boiling a solution of the nitrate above described, on a quantity of metallic lead. From being colourless it becomes yellow, and when cold deposits crystals in thin plates, which are

* Nicholson's Journal, 8vo, vol. viii. p. 283.

† Journal de Physique, tom. lvi.

less soluble in water than the crystals of the other nitrate. According to Dr Thomson's experiments, this salt rather differs in the proportion of the acid, than in the base being in a different state of oxidizement. He regards it as the neutral nitrate, while the other is a super-nitrate. It consists of 81.5 of oxide, with 18.5 of acid and water. By exposing either to heat, so as to cause a partial expulsion of the acid, a sub-nitrate is obtained in the form of a yellow powder, consisting of 86 of oxide, and 14 of acid and water*.

Muriatic acid acts very feebly on lead : even when assisted by heat, it oxidizes and dissolves but a small portion of it. With the oxide of lead it combines more easily, when the oxidizement is not at the maximum ; hence, when digested on the red oxide, it decomposes it, abstracts part of its oxygen, and forms oxymuriatic acid, while another part of it combines with the metal, thus partially de-oxidized. In these combinations there is always an excess of acid, which communicates solubility, and enables the salt to crystallize in small prisms, having a silky lustre. The neutral muriate is best obtained by adding muriatic acid, or rather a muriate, to the solution of any of the soluble salts of lead. The muriate is immediately precipitated. It is soluble in about 30 parts of water, and, by concentration of its solution, slender prismatic crystals are obtained. It is fused by heat, and forms, when cold, after its fusion, a grey semi-transparent mass, named Horn Lead. If the heat be continued, it is partly decomposed, partly sublimed. According to

* Nicholson's Journal, 8vo, vol. viii. p. 28 ; -8.

Kirwan, the crystallized muriate consists of 81.77 of oxide, and 18.23 of acid and water.

Oxymuriatic acid gas transmitted through water, in which red oxide of lead is put, changes the oxide, brings a portion of it to a higher state of oxidizement, which remains insoluble, probably combined with part of the acid, while, with another portion of the altered oxide, it enters into combination, forming what has been regarded as an oxymuriate, or hyper-oxymuriate. It is more soluble than muriate of lead : the solution has a yellowish colour, and affords, by the action of soda or potassa, a precipitate of a brownish-red colour.

Phosphoric acid acts on lead very slowly. But the phosphate of lead is at once formed by adding a solution of phosphate of soda to a solution of nitrate or acetate of lead, it being thrown down in the state of a white insoluble precipitate. The relations of fluoric and boracic acid to lead are similar ; the fluuate and borate of lead being formed by a similar process, and being thrown down in white insoluble precipitates. Both melt before the blowpipe into a species of glass.

Carbonic acid exerts an affinity to the oxides of lead, and the carbonate of lead can be formed by adding a solution of carbonate of soda or potassa to a solution of any of the soluble salts of lead, a copious white precipitate being formed. The paint named Cerusse or White Lead is a carbonate or sub-carbonate. It is prepared by exposing lead in thin sheets, coiled and inclosed in an earthen vessel, to the vapour of boiling vinegar, the heat being usually applied so as to produce this vapour, by placing the vessels in stable-litter, or tanners bark : the

metal is oxidized, and the carbonic acid is either formed from part of the acetic acid, or is absorbed from the air.

When this substance, cerusse, is boiled with vinegar, a salt is formed, the acetate of lead, or the sugar of lead of commerce, which is obtained by evaporation, crystallized in prisms. This, as a compound of acetic acid, is to be afterwards considered.

The salts of lead are in general decomposed by the alkalis, which throw down from their solutions precipitates, which are sub-salts, as Vauquelin observed *. When the fixed alkalis are employed in these precipitations, and added in excess, they re-dissolve part of the precipitate: they are also capable of dissolving the pure oxides. They seem even to favour the oxidizement of the metal by water or air. Some of the earths also, particularly lime, are capable, when boiled with water on the oxides of lead, of dissolving a portion of them; the solution affording minute crystals on evaporation. All the earths unite with these oxides by fusion, and form yellow glasses or enamels. No metallic oxide is so powerful in promoting the vitrification of earthy substances as oxide of lead.

Oxide of lead, from the strength of its attraction to acids, is capable, when aided by the circumstances which influence chemical affinity, of decomposing a number of the neutral salts. Thus, when triturated with muriate of ammonia, the pungent smell of the ammonia becomes apparent: if heat is applied, the ammoniacal gas is disengaged. It likewise decomposes muriate of soda; and this decomposition is of importance, as it has been employed

* Nicholson's Journal, 4to, vol. iii. p. 473.

on a large scale, as a method of procuring the alkali. It was first observed by Scheele; he having found, that, when four parts of litharge are mixed with one part of muriate of soda, and made into a soft paste with water, after some time soda is evolved, the acid being attracted by the oxide of lead, and by keeping the mixture soft, by the addition of water as it is necessary, the whole of the salt may be decomposed and the soda extracted by lixiviation. The process has been carried on in this manner in this country, the compound of the oxide of lead and muriatic acid being convertible by heat into a yellow paint, which in part defrays the expence. The theory of the operation formerly appeared very difficult to chemists; for soda is capable of decomposing neutral muriate of lead, abstracting the acid from the oxide; and, of course, the oxide could not be said to have a stronger attraction to that acid than the alkali had, in consequence of which, it decomposed the muriate of soda. Some chemists supposed the effect to be produced by the concurrent affinity of carbonic acid contained in the litharge in its usual state, or derived from the atmosphere. Vauquelin approached to the real solution, by referring it to the effect of the quantity of oxide of lead employed, expressing this, however, according to the views then entertained of chemical affinity. Muriate of lead, he supposed, had an attraction to an excess of oxide; hence, in the decomposition which the oxide of lead effects in muriate of soda, two affinities he supposed operate, by which it is effected,—the affinity of oxide of lead to muriatic acid, and of muriate of lead to an excess of oxide. The compound, therefore, which results, is a muriate with a great excess

of oxide; and, on this view, he explained why so much oxide was necessary to decompose the muriate of soda *. Without adopting this complicated view, involving in some measure the old absurd doctrine of disposing affinity, the effect must no doubt be ascribed simply to the circumstance of quantity, aiding so much the affinity of the oxide to the acid as to enable it to overcome the affinity of the soda to the acid; the entire decomposition from the former affinity being promoted by the insolubility of the sub-muriate of lead. In conformity to this explanation, it is found, that soda cannot deprive neutral muriate of lead of the whole of its acid, but abstracts only so much as to reduce it to a sub-muriate.

Lead forms no combination with Carbon. It unites very readily with Sulphur, by fusion, and forms a compound of a dark grey colour, having a metallic lustre, brittle, with a striated texture, and less fusible than the metal. By exposing it to a greater heat, much of the sulphur is volatilized. It is uncertain whether sulphur can be combined with the oxide of lead: when they are mixed and subjected to heat, the compound formed, as Vauquelin has remarked †, is similar to the metallic sulphuret; whence it appears, that the oxide is decomposed, its oxygen being attracted by a portion of the sulphur, and forming sulphuric or sulphurous acid, which the heat dissipates, while the remaining sulphur combines with the reduced metal. The result of the action of sulphuretted hydrogen on the oxides of lead is nearly the

* Nicholson's Journal, 4to, vol. iii. p. 470.

† Ibid. 4to, vol. v. p. 116.

same: when added to the solution of any of the salts of lead, a precipitate is immediately formed, of a very dark brown colour, approaching to black: this arises from the hydrogen of the sulphuretted hydrogen combining with the oxygen of the oxide, while the sulphur unites with the lead. The precipitate, it is remarked by Vauquelin, is similar to the native sulphuret, or galena, containing only a little more sulphur, which may be separated by the application of heat *. The action of the hydro-sulphurets, and probably of the sulphuretted hydro-sulphurets, is precisely similar.

The solutions of the salts of lead are so deeply blackened by sulphuretted hydrogen, that they have been employed as a sympathetic ink: letters traced with a very dilute solution on paper, becoming visible when the paper is exposed to sulphuretted hydrogen gas.

The action of sulphuretted hydrogen likewise affords a test by which the presence of lead may be detected; and as this test is sometimes used to discover the presence of lead in suspected wines or other liquors, it is of importance that it should be free from any ambiguity. The solutions of the alkaline sulphurets, which have been used, are liable to some fallacy; for although they precipitate lead of a very dark colour, yet they also throw down iron when it is in certain states of oxidizement, which may therefore be mistaken for the precipitate of lead; or the sulphur may be precipitated by the acid in wine, which may sometimes give rise to the same mistake. A test was given by Hahneman, as having the advantage of

* Nicholson's Journal, vol. v. p. 116.

precipitating lead with certainty, but not iron. It is prepared from sulphuret of lime, (formed by having exposed equal parts of sulphur and of oyster-shells to a white heat for 15 minutes), and super-tartrate of potassa. 120 grains of the former, and 180 of the latter, are put into a bottle, which is to be filled up with 16 ounces of water that has been previously boiled, and suffered to cool. The liquor, after having been repeatedly shaken, is allowed to become clear, by the subsidence of the undissolved matter : it is then poured into phials, which hold about one ounce measure ; into each of which, about 20 drops of muriatic acid have been previously put ; and they are well corked. One part of this solution, mixed with three parts of the suspected liquor, will discover, by a black precipitate, the smallest quantity of lead, while it does not precipitate iron ; the tartaric and muriatic acids retaining iron in solution when combined with sulphuretted hydrogen, and any acid in the wine having no effect in precipitating any of the sulphur of the test-liquor *. Perhaps, however, the simple solution of sulphuretted hydrogen in water is less liable to fallacy than any other test. A solution of sulphate of soda affords also a very good test, a white precipitate being formed when it is added to any liquor containing lead. And the utmost certainty is attained, by obtaining from any of these precipitates dried, and exposed to heat with a little charcoal in a small crucible, a globule of lead.

Lead combines with phosphorus, the compound being formed when phosphorus is projected on melted lead.

* Crell's Chemical Journal, vol. iii. p. 61.

The phosphuret has a colour approaching to that of lead, but whiter : it has the metallic lustre, but is liable to tarnish : it is soft, so as to be easily cut by a knife, flexible, and of a lamellated texture. Pelletier supposed it to contain, in 100 parts, from 12 to 15 of lead. It is partially decomposed, and the phosphorus volatilized, during fusion, especially before the flame of the blowpipe.

Lead combines with a number of the metals, but few of its alloys are applied to any useful purpose, that with tin excepted, which forms Pewter, and, in a different proportion, what is named Soft Solder. It is easily united with gold by fusion, and, in Mr Hatchet's experiments, was found, even in a very small proportion, to impair greatly the ductility of the gold : it, at the same time, debases its colour. It unites with silver with equal facility, and promotes the fusion of the silver, the compound being very fusible : the tenacity and hardness of the silver are also much impaired. This is one of those alloys in which the density exceeds the mean density of the two metals. By a continued heat, sufficient to keep it in fusion, with exposure to the atmosphere, the lead is oxidized, leaving the silver pure, as is displayed in the process of cupellation. With platina lead likewise combines, forming an alloy, in which the ductility of the platina is much diminished, and which is possessed of no valuable quality. By quicksilver lead is dissolved, and a series of combinations formed, varying according to the proportions, the fluidity of the quicksilver being diminished, and the consistence becoming even firm when the lead predominates, so as to admit of the compound assuming a crystalline arrangement. With copper, lead forms an

alloy of a grey colour. It can scarcely be combined with iron by fusion; the two metals appearing to remain distinct even when both are brought into fusion. In this case, however, according to Guyton*, each receives a portion of the other; so that two alloys, one of iron with a little lead, and another of lead with a little iron, are formed: the properties of these have not been particularly examined.

The uses of lead are extensive. As it is flexible, easily reduced to thin sheets, and easily united by solder, it is used in making pipes for conveying water, large boilers, and vessels of different kinds. It is cast into thin sheets for covering buildings. Its oxides are used as paints. They are also employed in the manufacture of the finer kinds of glass, to which they communicate density, a greater equality of texture, and a greater susceptibility of polish. From their vitrifying quality, and the greater refractive power which they communicate to glass, they enter into the composition of the pastes which imitate the gems: And they form, in combination with earthy matter, the glazing of the inferior kinds of earthen-ware. There is much reason to doubt, whether the use of lead in pipes for conveying water, or in vessels for containing it, be altogether safe; as lead, immersed in water, is covered at length with a white crust of oxidized lead; and this metal is the most insidious, and, at the same time, one of the most destructive of the mineral poisons. The use of earthen-ware glazed with it is also hazardous, as the glazing is soon eroded by any acid liquor, and a noxious im-

* Annales de Chimie, tom. xliii.

pregnation communicated ; and many fatal accidents have occurred from the use of lead in the fabrication of vessels in which wine, cyder, and other fermented liquors, are prepared or kept.

CHAP. XII.

TIN.

THIS metal is of a white colour, with considerable lustre: it has so much malleability, that it can be reduced by beating into very thin leaves : it has little ductility, however ; a wire, one-tenth of an inch in diameter, not supporting more than 50 lbs. without breaking. Its hardness is so inconsiderable, that it can be easily cut by a knife, and scratched by a number of the other metals. It is very flexible, and, in bending, gives a peculiar crackly noise : when rubbed, it emits a peculiar odour. It is one of the lightest of the metals ; its specific gravity, after fusion, being 7.291 ; after hammering, 7.299.

Tin, though a metal known from the most remote ages, is one not widely diffused : it is found even in comparatively few countries ; as in Cornwall in England ; in Gallicia in Spain ; in Saxony and Bohemia ; in the peninsula of Malaca, and, as has been affirmed, in Mexico. Its ores are comparatively few, there being only two species, the oxide and the sulphuret. The former of these is the only ore that is wrought to obtain the metal. Being freed, by washing, from the intermixture of

any stony matter, it is roasted, and then fused in contact with the fuel by a moderate heat. The tin of Cornwall is supposed to be purer than the German tin, though it is still inferior to the tin from India.

Tin melts at 416° of Fahrenheit; according to Mr Crichton, at 442° *. When slowly cooled, it crystallizes in rhombs.

When in fusion, and at the same time exposed to the action of the air, it becomes quickly oxidized: its surface first becomes dull, and is then covered with a grey powder. This is the metal in the first degree of oxidizement; and it has been supposed to contain from 8 to 10 of oxygen in 100 parts. If it be longer exposed to heat, and stirred frequently, it becomes of a yellowish-white colour, from a higher degree of oxidizement, and forms the substance named *Putty*, which is employed in polishing glass. When tin is exposed to a very strong heat in a crucible, or is subjected with an admixture of nitre to a temperature above ignition, it burns with a yellowish-white flame, and affords a similar oxide. This oxide appears to be capable of volatilization, and of forming, as it condenses, needle-like crystals. Precipitates are also thrown down from the saline combinations of tin, in which the metal is perhaps even more highly oxidized. Proust supposed, that the precipitate thrown down from the solution of tin in dilute nitric acid by potassa, is an oxide containing about 20 parts of oxygen in 100 parts; and the white powder, formed by the action of concentrated nitric acid on tin, an oxide containing 28 of oxygen. The former,

* Philosophical Magazine, vol. xv. p. 147.

as Berthollet *junior* has stated, is a sub-nitrate; the latter, he remarks, does not afford any traces of nitric acid by distillation, and appears to be nearly a pure oxide*.

The oxides of tin are fused with much difficulty: they are not decomposed by heat alone, but the oxygen is abstracted by carbonaceous matter at a high temperature. There is no metal which has so great a tendency as tin to pass to a highly oxidized state.

Tin loses its lustre from exposure to the atmosphere, but it does not rust from the action either of air or water. Even at a high temperature, water is not decomposed by it.

Tin is oxidized and dissolved by the greater number of the acids; and in these combinations, is particularly displayed the tendency of this metal to pass to a highly oxidized state. Its saline solutions are from this property capable of abstracting oxygen from many substances; and from the same cause they are not permanent, or, the metal continuing to attract oxygen from the acid, or from the air, becomes so highly oxidized, that its affinity to the acid is weakened, and it separates in the state of a salt with excess of base.

With the assistance of a moderate heat, tin decomposes the concentrated sulphuric acid, attracts oxygen from it, and disengages sulphurous acid gas: if the heat be high, even a portion of sulphur is evolved. The solution, on standing, deposits slender crystals: it is decomposed by the affusion of water, which throws down a white precipitate. If much of the tin has been dissolved by the a-

* Chemical Statics, vol. ii. p. 481.

cid, the solution is gelatinous. It is decomposed by heat; and even when kept for some time, the oxide attracts so much oxygen as to become insoluble. When the solution is made with an acid somewhat diluted, and in the cold, it is more permanent, and is not decomposed by water, partly from the lower state of oxidizement, and partly probably from an excess of acid.

Fourcroy and Vauquelin, in their experiments on sulphurous acid, examined the action it exerts on tin. When the tin is immersed in its liquid solution, it assumes a yellowish colour, afterwards becomes black, and lets fall in the fluid a black powder, which appears to be a sulphuret of tin, formed from the decomposition of the acid. Part of the tin being thus oxidized, combines with the acid; and this white sulphite, with a portion of sulphur also in combination with it, is likewise precipitated in the form of a white powder. A part of the oxide of tin still remains in solution in the liquid, combined with the remaining sulphurous acid *.

If nitric acid in its most concentrated state, or having a specific gravity of 1.48, be poured on tin-filings, there is no apparent action between them; but if it be a little diluted, or if, after the strong acid has been poured on the tin, a very little water be added, a very violent action is exerted, the acid is decomposed with great rapidity, copious red fumes are disengaged, and the temperature rises considerably. The tin is so highly oxidized, that it does not pass into a state of solution, but forms a white powder, in which, as has already been remarked, there

* Fourcroy's System, vol. vi. p. 38.

are even no traces of nitric acid, and which is therefore nearly a pure oxide.

If the acid be more largely diluted, as with three or four parts of water, and the tin added successively in small quantities, the temperature at the same time being kept low, the action is more moderate, the metal is less highly oxidized: it is therefore capable of combining with the acid, and thus a solution of nitrate of tin is formed.

In the solutions of tin in nitric acid, the metal exists in different degrees of oxidizement according to the strength of the acid, the temperature which has been applied, or the proportions of tin and acid used. In the solution prepared in the cold, and with a dilute acid, the metal, according to Proust, is in the state of an oxide, containing 30 of oxygen in 100, while the white powder formed by the action of a stronger acid, is oxidized to the extent of 40 *. Such is the avidity, too, of this metal for oxygen, that in all these cases of the action of nitric acid, whether concentrated or diluted, part of the water is decomposed, and hence a portion of nitrate of ammonia is always formed, the hydrogen of the decomposed water being presented in its nascent state to the nitrogen which is also evolved from the decomposition of the acid, and forming ammonia, with which part of the undecomposed acid combines. The presence of ammonia can be easily discovered, by adding lime in sufficient quantity, which soon produces the pungent ammoniacal smell.

The solution of nitrate of tin is not permanent: the metal continues to attract oxygen from the acid until it be-

* *Annales de Chimie*, tom. xxviii. p. 214.

come so highly oxidized as not to remain soluble. The same change is produced by heating the solution ; a precipitate being soon deposited, which is sub-nitrate of tin. If this precipitate be washed with an alkaline solution, the acid is abstracted, and grey oxide of tin remains *.

The action of muriatic acid on tin affords some important results. The metal is dissolved by the acid slowly in the cold, and more rapidly when the solution is promoted by heat, the tin receiving oxygen from the water, and this oxide combining with the acid. It has been often observed, that the hydrogen gas disengaged during this solution has a fetid smell ; and this, approaching to the arsenical odour, has been ascribed to the presence of arsenic, which the hydrogen holds in solution. According to the observation of Proust, the arsenic is deposited on the sides of the vessel when this hydrogen gas is burnt †. With regard to this, however, there may be some doubt ; as the experiments of Bayen, undertaken with the view of determining, whether the prejudice that has long prevailed, of tin containing arsenic, establish the conclusion, that in the tin of commerce there is often no appreciable quantity of arsenic, and that, when it can be discovered, it is extremely minute, never exceeding one grain, and often not half a grain in an ounce ‡,—a quantity evidently incapable of accounting for the odour of the hydrogen gas, and the appearance observed by Proust. It is not improbable that the odour and the deposition of any metallic matter may

* Chemical Statics, vol. ii. p. 481.

† Journal de Physique, tom. li. p. 175.

‡ Opuscules Chimiques, tom. ii. p. 274. 411.

rather be owing to the solution of the tin itself in the hydrogen gas.

The solution of muriate of tin is of a yellowish colour. By evaporation it may be crystallized in needle-like crystals, which are somewhat deliquescent. These dissolved in distilled water, according to the observation of Berthollet *junior*, render it milky, a precipitate being formed of sub-muriate of tin, while part of the salt, with an excess of acid, remains in solution, both the part dissolved and the part precipitated being in the same state of oxidizement. A similar precipitate is produced by the action of the alkalis, (when they are not added in excess, for, in this case, part of the precipitate is dissolved), and from this precipitate a portion of acid may be abstracted, by repeatedly washing it with water in the cold, or with a little heat: its colour thus changes from a white to a grey, but even in this state the oxide still retains a portion of acid *.

The oxide of tin in this combination, has a great tendency to combine with a large proportion of oxygen, and hence the solution of the muriate is capable of de-oxidizing a number of substances. . If added to the solutions of a number of metals, by attracting part of the oxygen of the metal dissolved, while it itself passes to the maximum of oxidizement, it produces precipitates composed of the oxides of the two metals. Thus, mixed with a solution of gold, it produces a purple precipitate; with a solution of copper, a white precipitate; and with other metallic salts, precipitates of various colours: the solution of nitrate of mercury is completely reduced by it: it attracts, too, the

* Chemical Statics, vol. ii. p. 475.

oxygen from metallic oxides, from sulphurous, nitric, and oxymuriatic acids, and absorbs oxygen when it is exposed to atmospheric air.

By such processes, a muriate of tin is formed at a higher degree of oxidizement, and which differs much in its properties from the other. This muriate used to be prepared by the older chemists, by exposing to heat in a retort, connected with a receiver, a mixture of an amalgam of five parts of tin, and one of quicksilver, with an equal weight of corrosive muriate of mercury; the oxygen and the muriatic acid of the latter salt are transferred to the tin, and the proportion of oxygen being large, that muriate of tin is formed, which is at the *maximum* of oxidizement. It is distilled by the heat applied, and condensed in the receiver: it forms a dense liquid, which exhales vapours on exposure to the atmosphere. To the older chemists it was known by the name of the Fuming Liquor of Libavius. Pelletier, in his researches on the combinations of tin and muriatic acid, gave another process for preparing it,—passing a current of oxymuriatic acid through a solution of muriate of tin, and expelling the excess of muriatic acid by the application of heat*.

This preparation obtained by the old process is in a highly concentrated state. A series of experiments were made upon it by Adet †, with the view of elucidating its properties. It owes its fuming property, according to these experiments, to its volatility when it is free from water; the vapours being produced by its combination

* Mémoires de Chimie, tom. i. p. 388.

† Annales de Chimie, tom. i.

with the humidity of the atmosphere ; and these vapours, when condensed, form even slender crystals. Its odour is acrid. It dissolves in water with a hissing noise, and the production of an elastic fluid. When combined with about a third of its weight of water, it forms a solid mass, which is capable of being fused by heat, and congealed by cold. It is sublimed by a gentle heat without decomposition.

Adet and Pelletier supposed, that this substance is a compound of oxide of tin with oxymuriatic acid. It is rather to be regarded, as Proust observed, as a compound of tin highly oxidized with muriatic acid. A fact which shows its chemical nature is, that when diluted, it is capable of dissolving a portion of metallic tin, without any disengagement of hydrogen gas ; and it then forms a solution similar to that in which tin is dissolved by muriatic acid.

The nitro-muriatic acid dissolves tin with great rapidity. When the acid is undiluted, the metal attracts so much oxygen, that a great part of the oxide falls down. To moderate the action, small pieces of the metal are added at a time ; one is allowed to dissolve before the other is added, and the vessel in which the solution is performed is kept surrounded with cold water. The acid thus takes up half its weight of tin. The solution is transparent and brown-coloured : in a short time it becomes of the consistence of a jelly, which after some time becomes firm, so that it can be cut with a knife. When it remains fluid, it is often rendered of a thick consistence, by the addition of half its weight of water, which decomposes the solution, and precipitates a quantity of oxide that remains dispersed through the fluid. The transparency of the jelly is thus changed, and it exhibits the colours of the opal.

If the fluid solution be heated, an effervescence is excited from the farther action of the metal on the acid : it loses colour, and on cooling is transparent and gelatinous. The solution of tin in the nitro-muriatic acid is of great utility in the art of dying, as a mordant ; the oxide precipitated from it serving as a bond of union between the colouring matter and the stuff. It also heightens several colours, especially scarlet from cochineal. In using it, much difficulty is experienced from the uncertainty of obtaining it in an uniform state, the tin being susceptible, in the combination, of various degrees of oxidizement.

The action of the other acids on tin, affords less important results. The phosphoric acid has scarcely any sensible effect upon it. When a solution of phosphate of soda is added to a solution of muriate of tin, a phosphate of tin is formed, and, being insoluble, is precipitated. By a similar process, fluat and borat of tin may be formed : they are both insoluble in water, and their properties have scarcely been particularly examined. The carbonate of tin has not been formed.

The alkalis are capable of combining with oxide of tin. When muriate of tin is decomposed by any of them, if the alkali is added in excess, the precipitate of sub-muriate, which is at first formed, is re-dissolved, and an appearance somewhat singular is produced : when the solution has stood for some time, a kind of metallic arborescence or vegetation is formed, as Proust observed. This, as Berthollet *junior* has remarked, is owing to the affinity of the alkali being greatest to the oxide which is at the maximum of oxidizement : in consequence of this, it causes one part of the oxide, which had been precipitated

from the muriate, and which it had dissolved, to pass to this state of high oxidizement, in which state the alkali remains in combination with it, while the other part, deprived of the greater part of its oxygen, returns nearly to the metallic state; and, as the change goes on slowly, its particles, in uniting, assume the peculiar arrangement which gives rise to the appearance observed *. The triple salts which are formed, when the alkalis added in excess re-dissolve the precipitate which they at first occasion in the solutions of tin, are even capable of crystallizing. That of muriate of tin and potassa, is in the form of a rhomboidal prism, as is also the muriate of tin and ammonia, and the muriate of tin and barytes. The muriate of tin and soda, as well as the muriate of tin and strontites, crystallize in slender acicular crystals. The muriate of tin and lime is deliquescent †.

The alkalis appear to be capable of dissolving the oxides of tin, independent of the presence of any acid; and in conformity to the law generally observed in the relation of the alkalis to metallic oxides, which is precisely the reverse of that observed by the acids, their attraction is more powerful to the oxide, as the degree of oxidizement is greater. The compound of oxide of tin and potassa, Proust observes, crystallizes in lenticular crystals.

Tin and its oxides decompose several of the neutral salts, especially the ammoniacal salts; the ammonia being disengaged on the application of heat, with hydrogen gas, when metallic tin is used. It deflagrates with the

* Chemical Statics, vol. ii. p. 477.

† Ibid. p. 478.

nitrites; and, from this affinity to oxygen, it decomposes the sulphates, converting them into sulphurets.

Tin combines with sulphur by fusion. The compound is less fusible than the tin itself: it is of a dark grey colour, and retains the metallic splendour; and is capable of crystallizing in cubes. It consists of 20 of sulphur, and 80 of tin.

Sulphur, combined with oxide of tin, forms a compound of a golden colour, and highly beautiful appearance, termed *Aurum Musivum*, or *Mosaic Gold*, and which has been used for ornamental purposes. Different methods may be employed to obtain this compound. The following is the process which was given by Woulfe.

Twelve parts of tin are melted in a crucible, and three parts of mercury added to it. The amalgamation of the two metals is to be completed by rubbing the mass to a fine powder. It is then to be intimately mixed by trituration, with 7 parts of flowers of sulphur, and 3 parts of muriate of ammonia. The mixture is put into a matrass, of which it fills one half, and exposed to heat as long as any white vapours are disengaged. On increasing the heat a little, sulphuret of mercury, with a portion of muriate of tin, sublimes, and the *aurum musivum* remains at the bottom of the matrass. If the process has been properly conducted, it is of a flaky texture, and rich yellow colour: if too much heat has been applied, common sulphuret of tin is formed.

The theory of the formation of this compound is intricate, but appears to be sufficiently illustrated by the researches of Pelletier *. The trituration of the mercury

* *Mémoires de Chimie*, tom. ii. p. 89.

with the tin, serves principally to divide, and, in some degree, to oxidize the latter metal. When the mixture of the amalgam with the sulphur and muriate of ammonia is afterwards exposed to heat, the muriatic acid causes the tin to be oxidized by the water present: a disengagement of hydrogen therefore takes place: the oxide of tin then combines with the muriatic acid, and the ammonia is extricated, which, combining with part of the sulphur, forms sulphuret of ammonia, and produces the white fumes that are disengaged. By the heat being now a little increased towards the end of the operation, the muriate of tin which had been formed is decomposed, the muriatic acid is disengaged, and the oxide of tin, attracting a portion of sulphur, forms the aurum musivum.

Several other processes, much more simple, were proposed by Pelletier, to prepare this compound. If 600 grains of sulphur be added to 600 grains of tin, dissolved in 4 ounces of muriatic acid, and the fluid be evaporated until it remain concrete; on exposing this mass to heat, muriate of tin, with a little sulphur, is sublimed, and the residuum is aurum musivum. It is obtained likewise, by exposing to heat mixtures of the sulphuret of tin, with corrosive muriate of mercury, or with red oxide of mercury, or a mixture of oxide of tin with an equal part of sulphur; or it may be formed in the humid way, by adding a solution of sulphuret of potassa to a solution of muriate or nitrate of tin: the precipitate is a compound of oxide of tin and sulphur: it is of a yellow colour, and, if heated alone, or in mixture with half its weight of

muriate of ammonia, and one fourth its weight of sulphur, is converted into the mosaic gold *.

It had been generally supposed, that the oxide in this combination is in a high degree of oxidizement. According to Proust, however, it is at the *minimum*, as he finds, that if it be formed by exposing to heat a mixture of sulphur and oxide of tin at the *maximum*, there is a copious disengagement of sulphurous acid gas, proving an abstraction of oxygen from the oxide, when it combines with the sulphur †. It is decomposed by heat, sulphurous acid being expelled, and sulphuret of tin remaining. When heated with nitre, it explodes with much violence. The acids do not decompose it. The fixed alkalis dissolve, and at the same time change its composition.

The alkaline sulphurets combine with tin by fusion; the compound being in part soluble in water. On adding an acid to the solution, a precipitate is thrown down of tin, probably partly oxidized, in combination with sulphuretted hydrogen.

Tin is coloured by sulphuretted hydrogen gas. The alkaline hydro-sulphurets form precipitates with its saline solutions. If the metal be at the *minimum* of oxidizement, the colour of the precipitate is a deep brown: if at the maximum, it is of a golden yellow colour, and appears to be similar to the *aurum musivum*. In intermediate degrees of oxidizement, various shades of colour, between brown and yellow, are produced ‡.

* Mémoires de Chimie, tom. ii. p. 92-9.

† Nicholson's Journal, vol. xiv. p. 40.

‡ Chemical Statics, vol. ii. p. 474.

Tin combines with phosphorus ; the compound being formed by throwing small pieces of phosphorus on melted tin : it contains, in 100 parts, from 15 to 20 of phosphorus. It is of a silver-white colour, and a foliated texture : it is soft, so that it can be cut with a knife ; and it can also, in some measure, be flattened under the hammer. It inflames, when thrown on burning fuel. This compound can be also formed, by fusing in a crucible tin-filings and concrete phosphoric acid, one part of the tin combining with the oxygen of the phosphoric acid, the other with the phosphorus.

Tin combines with the greater number of the metals, and several of its alloys are in common use. There is a greater consumption of it, indeed, in the formation of these alloys, than for any purposes to which it is immediately applied. An opinion had very generally prevailed, that when combined even in a very minute proportion with gold, it destroyed its ductility, and rendered it perfectly brittle. Mr Alchorne shewed that this was an error ; as gold may be alloyed with even $\frac{1}{24}$ of tin, and still remain sufficiently ductile to be laminated, and to be drawn into fine wire. His experiments were repeated by Tillet, who concluded, that gold alloyed with tin acquires rigidity and hardness, and that though it may be beat out, it cannot be annealed so as to bear extension to any great degree of thinness *. Mr Hatchet, however, in his researches on the alloys of gold, has confirmed the conclusions of Alchorne ; and the common opinion, as well as the results of Tillet's experiments, must have arisen from

* Nicholson's Journal, 4to, vol. ii. p. 140.

the presence of lead, antimony, bismuth, or zinc, in the tin of commerce, any of these metals rendering gold very brittle. The alloy of gold and tin is possessed, however, of no valuable quality : the colour is pale, and when the tin amounts to one-tenth, the ductility of the gold is considerably impaired, especially at a high temperature. The tin is not easily abstracted from the gold. Tin has been supposed to be equally destructive of the ductility of silver as of gold ; but on this subject accurate experiments are wanting. The alloy is hard, its colour is bluish-grey, and it has a specific gravity greater than the mean specific gravity of its ingredients. With platina and tin a compound is formed, brittle and very fusible when the proportions are equal parts ; but when one part of platina is combined with 12 parts of tin, the alloy is more ductile. Quicksilver dissolves tin readily, amalgams being formed of various degrees of consistence according to the proportions. With four parts of tin, and one of quicksilver, it is solid, and capable of crystallizing.

A series of alloys is formed from the combination of copper with tin, sufficiently important to require more particular notice. The combination appears to have a tendency to form in certain proportions, regulated in some measure by the specific gravities and fusibilities of the metals ; for, when kept in fusion, and allowed to cool without agitation, two alloys are formed, the under part of the mass being one of copper, with a small portion of tin, and the upper part tin, with a small proportion of copper, while between these there is probably a gradation. By agitation the separation is counteracted. In general, tin lessens the ductility of copper, while it renders it more

hard, rigid, and sonorous ; these qualities being possessed in various degrees by the different alloys, according to their proportions, the hardness and brittleness being greater as the tin predominates. The density of the compound is also always greater than the mean density ; the contraction from the combination being so great, according to an experiment by Dr Pearson, as one-eighth. The principal of these alloys are bronze, bell-metal, the metal of which pieces of artillery are cast, and that which has been used for the mirrors of reflecting telescopes. Bronze is the one in which the proportion of tin is least, not exceeding 10 or 12 parts in 100. It is of a greyish-yellow colour, harder than copper, less liable to rust, and more fusible, so as to run thin, and be easily cast in a mould. Hence its use in the casting of statues. The metal that pieces of artillery are cast from, is of similar composition. It appears that an alloy perfectly similar to bronze was much in use among the ancients : swords, darts, and other warlike instruments were formed of it, as were also various utensils. According to Dr Pearson's experiments made on various ancient instruments of this kind, the alloy appears to have consisted of about eight or nine parts of copper, with one of tin ; and, as he justly remarks, this alloy still affords the best substitute for iron or steel : while the art, therefore, of manufacturing malleable iron was imperfectly known, and difficult to be practised, it must have been much used *. The hardness of this alloy observed in ancient arms, had even given rise to an opinion, that the ancients were acquainted with a method of hardening cop-

* Philosophical Transactions, 1796, p. 395.

per, which had been lost. Of this alloy, medals and coins were also often formed, as appears from the experiments of Dizé on several Greek, Roman, and Gallic coins, which consisted of copper and tin alone*. When the proportion of tin is increased, the alloy is rendered more brittle, and also highly sonorous; hence bell-metal is an alloy of this kind: the proportion of tin varies from one-third to one-fifth of the weight of the copper, according to the size of the bell, and the sound required. When the proportion of tin is still greater, an alloy is formed of a white colour, and which, from the closeness of its texture, and its susceptibility of a fine polish, exceeds any metal in the property of reflecting light: hence its adaptation to the purpose for which it is used,—the forming the speculum of reflecting telescopes: it has also the important advantage of not being liable to tarnish on exposure to the air. The proportion in which these qualities were best attained, appeared, from the experiments of Mr Mudge, to be a little less than one part of tin, with two parts of copper†. Mr Edwards, by an extensive series of experiments on the proportions of these metals, and the effects of different additions, succeeded in forming alloys much superior in brightness to those that had been before used. That which he preferred, was composed of 32 ounces of copper, with 15 or 16 ounces of tin, according to the purity of the copper, to which were added brass, arsenic, and silver, of each one ounce; the copper and the tin being melted in separate crucibles, when in fusion the one being

* Journal de Physique, 1790, p. 272.

† Philosophical Transactions, vol. lxvii.

added to the other, and the composition when well stirred being poured into cold water : the other metals are added in a second fusion : the arsenic appears to give a greater degree of density and compactness to the alloy, the brass more tenacity, and the silver adds to the whiteness *. According to the still more recent experiments of Mr Little †, the silver renders the alloy too soft to admit of it receiving a high polish. The composition which he has recommended is 32 parts of bar copper, 4 parts of brass, $16\frac{1}{2}$ parts of tin, and $1\frac{1}{4}$ of arsenic.

From the affinity between tin and copper, a thin layer of the former metal can be easily applied to the surface of the latter ; and this practice of tinning, as it is named, is often applied to prevent the erosion or rusting of copper-vessels, and the noxious impregnation which they would of course communicate to liquors kept in them. The surface of the copper is polished so as to be quite bright : sal ammoniac is applied to it when hot, by which the oxidation appears to be prevented ; or pitch is sometimes used for the same purpose ; the melted tin, or, what is often substituted, on account of its hardness being greater than that of pure tin, an alloy of tin and lead, is applied to the surface of the copper, to which it adheres.

Tin and iron may be combined by fusion. In this, as in many other metallic combinations, two alloys are established, differing in the proportions, in the different parts of the same mass. The one, that in which a small pro-

* Nicholson's Journal, 4to, vol. iii. p. 490.

† Transactions of the Irish Academy, vol. x. or Nicholson's Journal, vol. xvi. p. 33.

portion of iron, about $\frac{1}{12}$, is combined with tin, is malleable, harder than tin, but still sufficiently soft to be cut by the knife; the other again, in which iron is alloyed with a smaller portion of tin, is much harder, is slightly malleable, and not easily fused. On the affinity between iron and tin, is founded the art of forming tinned iron, or what in this country is named White Iron. Thin plates of malleable iron cleaned, are dipped into a vessel of melted tin, the surface of which is protected from oxidizement by the air, by a thin layer of melted tallow, the tin unites with the iron at each surface: it is doubtful whether it penetrates the entire substance of the iron, as has been generally supposed. The iron thus acquires a white colour, is rendered less liable to rust; its ductility is little impaired: hence the plates can be easily bent, and from the alloy of tin at the surface can be also easily soldered.

Tin and lead, differing little in their fusibilities, can be united in all proportions. The lead, by an addition of tin, acquires greater hardness; and hence this alloy is frequently used. It forms the compound metal named Pewter; into the composition of which, however, zinc and copper sometimes enter. The alloy of equal parts of tin and lead, forms the soft solder used in soldering tinned iron plates.

The amalgam of tin is used in covering the backs of glass mirrors. Tin in thin leaf is laid on a smooth stone table; and quicksilver being poured over it, it is extended over the surface by a rubber of cloth: the surface of the tin leaf becomes slightly oxidized, and this film of oxide is removed by the rubber. More quicksilver

is then poured over the tin, so as to cover it to the thickness of a line. The glass is applied in a horizontal direction at one end of the table, and is pushed forward so as to remove before it the oxide at the surface of the amalgam. Weights are then placed on it, to press it down, and force out the superfluous quicksilver, and a thin crust of amalgam adheres to the glass, giving the property of reflecting the light which falls on its anterior surface.

It is principally in the formation of these different alloys that tin is used. Its oxides are employed in enamelling and in polishing the metals; and its solution in nitro-muriatic acid, is extensively used as a mordant in the art of dyeing.

CHAP. XIII.

ZINC.

THIS metal was unknown to the ancients, though they were acquainted with one of its ores, calamine, and the effect which it has of converting copper into brass. It appears to have been discovered during the researches of Alchemy. Swab and Margraaf gave the process by which it may be extracted from its ores, by distillation. The method of extracting it seems also to have been long known in India and China; the metal which had been brought from these countries into Europe under the name of Tutenag, being principally zinc *.

* Bergman's Essays, vol. ii. p. 311.

This has usually been ranked among those metals, which, from their very imperfect ductility and malleability, have been named Semi-metals. It was known, however, that, by uniform pressure, it might be extended into thin plates; and more lately, it has been discovered, that, at a certain temperature, it has so much malleability and ductility, that it can be lamellated, and drawn into wire, for which a patent has been obtained by Messrs Hobson and Sylvester of Sheffield. The temperature at which it possesses these properties, is between 210° and 300° of Fahrenheit; and by keeping it in an oven at this heat, it may be extended without difficulty. By being annealed, it retains this tenacity so as to be easily bent *. At a higher temperature, it is brittle, so as to fall to pieces under the hammer.

Zinc is of a white colour, with a shade of blue, and, in a fresh fracture, is possessed of considerable lustre. It is hard, so that although it can be scratched, it is not easily cut, by a knife. Its texture is striated, the striæ being of considerable breadth. Its specific gravity is 7.190.

The ores of zinc are not numerous: there are only two species, what have been named Calamine and Blende. The first is an oxide, frequently with a portion of carbonic acid; the other is a sulphuret. From either of these it was for a long time found difficult to extract zinc, owing to the circumstance that it is volatilized by heat. On this, however, was at length founded the process of obtaining it by distillation. It had long been practised in China; and in Europe it was first established in England,

* Nicholson's Journal, vol. xi. p. 304.

and is now extensively carried on. Calamine is the ore that is usually wrought. Being pounded, it is calcined so as to expel any carbonic acid; it is then mixed with charcoal: the mixture is put into conical pots, closed at the head; an open iron tube being fixed in each, reaching nearly to the top, and descending through the bottom, passing through the floor of the furnace, and terminating in a vessel of water. Heat is applied around the pots, so as to reduce and volatilize the zinc; the vapours of which, passing through the tube, are condensed in the water. When the extraction of zinc from blende is attempted, it is volatilized in a furnace, the vapours being received in a bed of charcoal.

This metal melts a little before ignition, or nearly at 700° of Fahrenheit. When heated near to its melting point, it is so brittle, that a blow of a hammer reduces it to powder. Its crystallization is difficult. Pelletier obtained it in flattened hexaedral prisms*. In close vessels, by an increase of heat, it is volatilized without change.

When zinc is melted in contact with the air, its surface soon becomes covered with a grey powder, which is an imperfect oxide, or the metal in its first degree of oxidizement. If the temperature is raised to ignition, or a little higher, it burns with a bright flame, at first of a greenish or yellowish shade, but which, as the heat is increased, becomes of a dazzling white: a white oxide is formed, which is carried up in very light flocculi, which have hence been termed the Flowers of Zinc, or Philosophers Wool. The apparent volatilization of the oxide,

* *Mémoires de Chimie*, tom. i, p. 58.

is owing to the volatility of the metal and the motion of the air, as by itself it is not volatile. It remains fixed in a crucible in a very strong heat. When urged by an intense heat, it is vitrified; the glass having a beautiful yellow colour. In this operation, the oxide loses a little oxygen. It is not completely reduced but by exposure to heat, with substances capable of affording carbon, which attracts its oxygen. Zinc, in its vivid combustion, gains 17 parts by weight in 100, or perhaps a little more, if allowance be made for the portion lost by the rapid current of air carrying it off. According to Proust, the white oxide, which is formed by this combustion, consists of 80 parts of zinc, and 20 of oxygen*. Clement and Desormes have stated its proportions at 18 of oxygen and 82 of zinc: after having been urged by a strong heat, until it acquire a yellow colour, it contains only about 11 of oxygen†. According to Vauquelin, the oxide of zinc, which exists in some of its saline combinations, as the sulphate or nitrate, contains 0.21 of oxygen‡.

Zinc is little acted upon by water, at the common temperature of the atmosphere; but, at ignition, the water is rapidly decomposed; the metal attracting its oxygen, and a large quantity of hydrogen gas being disengaged. This experiment is difficult to make, as the metal is always volatilized by the necessary degree of heat.

Zinc is oxidized and dissolved by the greater number of the acids.

The concentrated sulphuric acid requires the assistance

* *Annales de Chimie*, tom. xxxv. † *Ibid.* tom. xlii.

‡ *Ibid.* tom. xxviii. p. 50.

of heat: the metal is then oxidized, and sulphurous acid gas is expelled. When diluted with 3 or 4 parts of water, the oxidizement and solution go on rapidly in the cold; the metal decomposing, not the acid but the water, and hence the gas which is discharged is hydrogen: the oxide of zinc combines with the acid. More or less of a black powder separates during the solution, which has been generally supposed to be carbon or plumbago that had been combined with the zinc. According to Proust's assertion, it is a mixture of arsenic, lead, and copper.

When this solution is filtered, it is colourless, and, when concentrated by evaporation, affords crystals, which are slender prisms of four sides, acuminated by four planes. This salt, the sulphate of zinc, has a styptic taste; is soluble in three times its weight of water at the temperature of 60° ; and undergoes the watery fusion, when moderately heated. According to Mr Kirwan, it consists, in its crystallized state, of 40 of oxide of zinc, 20.5 of acid, and 39 of water. Mr Smithson has stated, that, when freed from water, it is composed of 50 parts of oxide, and 50 of acid.

Sulphate of zinc is prepared in the large way, from some varieties of the native sulphuret. This ore is roasted, moistened, and exposed to the atmosphere: the sulphur attracts oxygen, and is converted into sulphuric acid: the metal is, at the same time, oxidized, and, of course, combines with the acid. The sulphate of zinc, thus formed, is after a certain time extracted from the materials by washing: the solution is not prepared so as to crystallize, but is evaporated to dryness, and run into moulds. It is therefore in hard masses, of a granulated

texture, and a yellowish-white colour. This is the white vitriol of commerce. It generally contains a small portion of iron, and sometimes of lead.

Sulphurous acid dissolves zinc, sulphuretted hydrogen gas being formed from the decomposition of a portion both of the acid and of the water. On exposure to the air, it deposits needle-like crystals, which, according to Fourcroy and Vauquelin, are sulphuretted sulphite of zinc. By dissolving oxide of zinc in sulphurous acid, the pure sulphite is obtained. It is soluble and crystallizable.

Nitric acid acts upon zinc with great violence : it is decomposed with a rapid effervescence ; and nitric oxide, and nitrous oxide gases, with nitrous acid vapour, are disengaged : the temperature of the solution is at the same time considerably raised. The nitrate of zinc is best obtained by using a dilute acid : by evaporation and cooling, the solution crystallizes in hexaedral prisms, acuminate by four planes. These are deliquescent, soluble in water and alkohol : they are decomposed by the gentlest heat, and detonate when thrown on ignited fuel.

The Muriatic acid likewise dissolves zinc with rapidity : the water mixed with the acid being decomposed, and hydrogen being of course disengaged. The solution does not afford crystals by evaporation, but becomes gelatinous. By urging the heat, this is partially decomposed ; part of the muriatic acid is expelled, and another part of the muriate of zinc is sublimed, and condenses in a mass, consisting of a congeries of prisms.

Phosphoric acid, in its liquid state, dissolves zinc with a disengagement of hydrogen gas, forming a solution which does not crystallize, but, by evaporation, becomes

gelatinous, and by a strong heat may be melted. The concrete phosphoric acid, heated with zinc-filings, is decomposed. Fluoric acid also dissolves zinc, hydrogen gas being evolved. Boracic acid, digested with it, becomes milky; and an insoluble borate of zinc is precipitated, on adding a solution of borax to a solution of muriate or nitrate of zinc. Carbonic acid, combined with water, dissolves a small quantity of zinc, and dissolves still more readily the oxide of zinc: when the liquid is exposed to the air, a thin iridescent pellicle forms on its surface, probably from the escape of the carbonic acid.

The salts of zinc are decomposed by the alkalis; the oxide, probably retaining a portion of acid, being precipitated. If a larger quantity of alkali be added, the precipitate is re-dissolved. The alkalis likewise dissolve the white oxide of zinc in its pure state. On this solubility of oxide of zinc in the alkalis, Vauquelin founded a method of analysing brass, which is a compound of zinc and copper; the brass being dissolved in dilute nitric acid; the solution being decomposed by a solution of potassa, and the precipitate being submitted to the action of a fresh quantity of the alkaline solution: the oxide of zinc is dissolved, while that of copper remains insoluble, and thus their proportions can be discovered. The fixed alkalis even act on metallic zinc, and promote its oxidizement by the oxygen which water holds dissolved, or even by the decomposition of water itself, as a little hydrogen gas is observed to be disengaged. Liquid ammonia exerts on metallic zinc a similar action.

From the strong affinity which zinc exerts to oxygen, it decomposes the greater number of the metallic salts,

de-oxidizing either partially or completely the oxides which enter into their composition.

Zinc appears to be soluble in small proportion in hydrogen gas. When water is decomposed by zinc, aided by the affinity of an acid, the hydrogen which is disengaged has been supposed to hold a small portion of zinc dissolved, which it deposits in burning in the state of a white oxide.

Carbon does not combine with zinc in any sensible quantity; yet zinc in the state in which it is usually met with in commerce, deposits, while dissolving in an acid, a quantity of a black powder, in which carbon has been supposed to be contained, this powder having been generally considered as carburet of iron. According to Proust, it consists of arsenic, with some other metals*.

Zinc cannot be directly combined with sulphur. When they are exposed together to heat, the sulphur is volatilized, and the zinc remains uncombined with any of it; yet their combination exists in nature, unless, indeed, blende be rather a sulphuretted oxide of zinc, as has been supposed. The oxide of zinc can be combined with sulphur by fusion, and a compound is formed of a brown colour, which, by sublimation, affords needle-like crystals of a yellow colour. The alkaline sulphurets do not dissolve the metal. Sulphuretted hydrogen added to the solutions of its salts, throws down a white precipitate, which is probably a hydro-sulphuretted oxide of zinc.

Zinc may be combined with phosphorus, by projecting small pieces of phosphorus on zinc melted in a crucible,

* Annales de Chimie, tom. xxxv. p. 52.

the zinc being covered with a little resin to prevent its oxidation. The phosphuret of zinc is of a white colour, with a shade of bluish-grey; has metallic lustre; is a little malleable; and burns when exposed to heat. Phosphorus appears also to combine with oxide of zinc. It is formed either when zinc and phosphorus are exposed to heat in a retort, or when phosphoric acid and zinc, either with or without a little charcoal, are heated together. In the first process, a red-coloured sublimate is formed, and also a sublimate consisting of needle-like crystals, with metallic lustre, and of a bluish colour. Both these, Pelletier, who performed the experiment, regarded as compounds of phosphorus with oxide of zinc. In the second process, needle-like crystals are sublimed, of a silvery white colour, which he also considered as a phosphuretted oxide of zinc. It is highly inflammable*.

Zinc combines with a number of the other metals. With gold it forms alloys of a pale colour, more hard and brittle as the zinc predominates: that from equal parts of the two metals is of a white colour, receives a very fine polish, and does not tarnish. A very small portion of zinc is sufficient, as appears from Mr Hatchet's experiments, to destroy the ductility of gold. Keeping them in fusion in separate crucibles near each other, has even this effect. The ductility of silver is also impaired by zinc. Platina forms with it a hard brittle alloy, of a bluish colour. It combines with quicksilver, either by trituration or applying heat, when it forms a kind of granular mass, which, when solid, from a sufficient propor-

* *Mémoires de Chemie*, tom. ii. p. 45.

tion of zinc, is capable of crystallizing. A soft amalgam of this kind is applied to the rubber of the electrical apparatus for exciting electricity by friction.

The most important alloys of zinc, are those which it forms with copper. The two metals may be united by fusion, but the operation requires particular management to prevent the volatilization or oxidizement of the zinc, and is therefore difficult. It is more easily effected by the process named Cementation. This consists in exposing to heat a mixture of calcined calamine and charcoal with granulated copper, or more usually, stratifying it with plates of the metal : the zinc is reduced, and being volatilized is applied in the state of vapour to the copper, by which the combination between them is effected ; and this compound can afterwards be easily combined by fusion, with additional proportions either of copper or zinc.

The compounds of zinc and copper differ in their properties according to the proportions in which they are united : all of them have a rich yellow colour, which is deeper according as the copper predominates. Brass is the alloy of this kind which contains the largest quantity of zinc ; the proportion being about one part to three of copper. It is of a fine yellow colour, is more fusible than copper, and is therefore more easily cast : it is much less liable to tarnish from exposure to the air, and it possesses likewise a considerable degree of malleability and ductility, as it can both be beat into thin leaves, and drawn into fine wire. Its specific gravity is greater than the mean specific gravity of the two metals. With a larger proportion of copper, other alloys are formed of a deeper colour, inclining to red ; such are princes-me-

tal, pinchbeck, and tombac. They are formed by fusing brass with an additional quantity of copper.

Zinc does not easily combine with iron, from the great difference in their fusibilities, and the volatility of the zinc. Yet that they may be combined is proved, by the coating of zinc which iron plates may acquire when immersed in melted zinc. With lead it can be united by fusion without difficulty. The alloy is harder than lead, of a whiter colour, and has some malleability, the hardness being greater as the zinc predominates. With tin an alloy is formed, which is harder than the tin, of a close grain, and has some ductility.

Zinc is principally used in the formation of some of these alloys, particularly those of copper, though now that the method of extending it into thin plates and into wire has been discovered, it may be applied to other purposes; and, in particular, may probably be used with advantage for several of the purposes to which lead has been applied.

CHAP. XIV.

NICKEL.

THE principal ore of this metal had been known to mineralogists, without its particular nature having been discovered, until Cronstedt, in 1751, shewed that nickel can be extracted from it, and that the metal thus obtained is different in its characters from every other. As it has a resemblance in some of its properties to cop-

per, and as it is also always magnetic, it was regarded by some chemists as an alloy of copper and iron, with a portion of arsenic. Bergman undertook the investigation of its properties, and, though he found it extremely difficult to obtain it pure, he established its claim to be regarded as a peculiar metal. It had been ranked among what are named the Semi-metals, from appearing to have little ductility or malleability. This is owing, however, to the intermixture of other metals, particularly of arsenic, which appears always to communicate brittleness to other metals. More recent researches, particularly those of Richter, have shewn, that when obtained pure, it is both ductile and malleable. It may be forged into very thin plates, their thickness not being greater than 0.01 of an inch. Its colour is white, intermediate between that of silver and tin, and is not altered by the air. It is nearly as hard as iron. Its specific gravity is 8.279, and when forged 8.666*.

The species of nickel ores are, its alloy with arsenic with a little sulphur, Kupfer-nickel, as it is named, and its oxide. It is from the former that the metal is extracted, but it is extremely difficult to free it entirely from the other metals with which it is associated. The process of Cronstedt was to roast the ore, to expel the volatile principles: the residual matter was mixed with two or three times its weight of black flux, and melted in a forge: a metallic button was thus obtained, in which, however, the nickel is still alloyed with arsenic, cobalt, and iron. Bergman endeavoured to obtain it pure by va-

* *Annales de Chimie*, tom. liii. p. 173.

tious processes, as by repeated calcinations and scorification ; and yet, after the sixth roasting with a strong fire, and reduction, it still continued to exhale an arsenical odour ;—by fusing it with sulphur and borax, or with an alkaline sulphuret ; by repeated scorification with nitre ; and in the humid way, by solution in nitric acid, and reduction of the nitrate, or decomposition of it by potash, and re-dissolving the precipitate in ammonia. Yet, after all, he found reason to conclude, that it is scarcely possible to obtain a complete purification of nickel *. Other methods have since been employed, by different chemists, as by Klaproth †, Chenevix ‡, Philips §, Thenard ||, Bucholz ¶, and Richter †. The process given by Chenevix is the most simple. The metal obtained from kupfer-nickel by the usual process, is dissolved in nitric acid, the solution being boiled, so that the arsenic present, receiving oxygen from the acid, may be converted into arsenic acid : a solution of nitrate of lead is then dropt in, and the liquor evaporated by a very gentle heat, but not quite to dryness. Alcohol poured into this solution precipitated every salt but the nitrate of nickel, which had been formed by the double decomposition of the arseniate of nickel and the nitrate of lead. The alcohol of the solution of nitrate of nickel being evaporated, the metallic salt was re-dissolved in water, and decomposed by po-

* Chemical Essays, vol. ii. p. 257.

† Kirwan's Mineralogy, vol. ii. p. 459.

‡ Nicholson's Journal, 8vo, vol. iii. p. 287.

§ Philosophical Magazine, vol. xvi. p. 312.

|| Ibid. vol. xx. p. 63. ¶ Ibid. vol. xxiii. p. 193.

† Annales de Chimie, tom. liii. p. 164.

tassa. The oxide, well washed and dried, was reduced in a Hessian crucible lined with lamp black. In the process followed by Thenard, which appears well adapted to remove every foreign metal, the impure nickel being roasted until it ceased to exhale arsenical vapours, was dissolved in nitric acid ; during the solution, the bismuth it contained, was separated in combination with arsenic acid, in the form of a white insoluble powder. To the solution, sulphuretted hydrogen was added, by which a small quantity of copper was precipitated. To separate the remaining arsenic, the solution was saturated with potash, and the metallic oxides existing in the solution were precipitated : though part of the arsenic was retained in the state of acid, in combination with the potash, a part was still also contained in the precipitate. It was therefore re-dissolved in nitric acid, and into this solution an excess of hydro-sulphuret of potassa was poured : the arsenic acid remained in the liquor combined with the alkali, while the other oxides were precipitated in combination with sulphur and sulphuretted hydrogen. These were the oxides of nickel, cobalt, and iron : they were put into a matrass with nitric acid : a solution was obtained, from which the pure oxides were again precipitated by potassa. And, lastly, to separate them from each other, they were agitated with oxymuriatic acid saturated with lime : they thus passed to the maximum of oxidizement. Oxide of nickel in this state is soluble in ammonia, while the oxides of iron and cobalt are not. Liquid ammonia being applied, therefore, a solution of the pure oxide of nickel was obtained ; and the ammonia being volatilized by heat, it was obtained of a beautiful green colour, and

reduced by exposure to heat in a Hessian crucible, mixed with oil, lamp black, and borax.

By the experiments that have been made on nickel in its pure state, it appears to be proved, that it is possessed of magnetic power, and that therefore iron is not the only metal to which this belongs. The magnetic property of nickel had often been observed; but as, in the usual processes by which it is obtained, it is always alloyed with iron, it was concluded, with probability, that the magnetism it exhibited was owing to the presence of this metal. Since methods, however, have been discovered of obtaining nickel in a purer state, the error of this conclusion has been discovered. The magnetic property is found in it when there are no traces of iron, and instead of being weaker as the nickel is purified, which it ought to be did it depend on any intermixture, it actually becomes stronger, and is nearly equal to that of iron; so much so, indeed, that, as Thenard has observed *, if it depended on iron, the nickel must be supposed to contain half its weight of that metal, while not the least trace of it is discovered by re-agents, which can discover it, if it were present to the amount of one-hundredth of the mass. Mr Chenevix, indeed, supposed that he had at one time established the fact, that when nickel is completely freed from iron it is not sensibly magnetic; but he afterwards discovered, that the loss of the magnetic property was owing to the presence of arsenic, with which the nickel had still been alloyed: when this was abstracted, the property appeared, and it was again destroyed when a little arsenic was add-

* Philosophical Magazine, vol. xx. p. 69.

ed *. Nickel, therefore, must be allowed to be magnetic. The effect of the magnet on it is very little inferior to that which it exerts on iron ; and the metal itself becomes magnetic by friction with a magnet, or even by beating it with a hammer †. Magnetic needles have even been constructed of it in France, and have been preferred to those of steel, as resisting better the action of the air. The nickel preserves its magnetic property when alloyed with copper, though it is somewhat diminished : by a small portion of arsenic, it is completely destroyed.

Nickel is extremely infusible ; its fusing point being higher than that of iron. Thenard, in reducing its oxide, was unable to melt the metal completely in the heat of a forge, in which a Hessian crucible began to fuse, and in which malleable iron was melted without any addition : he obtained only small metallic globules, interspersed in a mass imperfectly agglutinated ‡. The experiments of Richter || agree as to the difficult fusibility of nickel with those of Thenard ; and if in other experiments it has appeared more fusible, this has been probably owing to the alloy of other metals. In Thenard's experiments, nickel appears to have been even volatilized, metallic particles being found adhering to the cover of the crucible.

This metal is oxidized by exposure to atmospheric air at a high temperature, though with difficulty. Its oxide is more easily obtained by exposure to heat with nitre ;

* Nicholson's Journal, 4to, vol. v. p. 287.

† Annales de Chimie, tom. liii. p. 175.

‡ Philosophical Magazine, vol. xx. p. 68.

|| Nicholson's Journal, vol. xii. p. 77.

it is of an apple-green colour, and is obtained likewise of this colour by precipitation from some of its saline combinations. It appears to be the oxide at the *minimum* of oxidizement; at least, according to the experiments of Thenard, another oxide can be formed more highly oxidized. It may be obtained by exposing the green oxide to a red heat, or by treating it with oxymuriatic acid, or oxymuriate of lime. It is of a black colour, is soluble in sulphuric and nitric acids, with a disengagement of oxygen; and in muriatic acid, with a production of oxymuriatic acid*. It appears, therefore, to be too highly oxidized to be capable of directly combining with the acids. According to Richter †, oxide of nickel is reduced by heat alone; and the only difficulty experienced in this reduction is the intensity of the heat required to fuse the metal.

Nickel is oxidized and dissolved by a number of the

* Philosophical Magazine, vol. xx. p. 67.

† Richter, in reducing the precipitate obtained from a solution of nickel, obtained only metallic globules, interspersed in a scorified matter of a black colour. In some subsequent experiments*, he found that this matter could not be reduced by heat alone; but that when mixed with charcoal powder, and exposed to a very strong fire, it suffered reduction. The metal obtained was of a grey colour, hard and brittle, attracted by the magnet, but not so strongly as either iron or nickel. It is more fusible than nickel: in many of its properties it resembles this metal, while it differs from it in others. Richter regards it as a different metal, and has given it the name of Nickeline. Farther experiments must determine its nature.

* Nicholson's Journal, 8vo, vol. xii. p. 262.

acids; its solutions being in general of a green colour, and crystallizable.

Sulphuric acid acts very weakly on nickel: when boiled on it, sulphurous acid is disengaged, and a grey-coloured mass remains, partly soluble in water, and communicating to it a green tinge: by evaporation either of this solution, or of that of the oxide of nickel, in sulphuric acid, crystals in tables, or in short prisms, of a pale emerald green colour, are obtained.

Nitric acid acts rapidly on impure nickel: when the nickel is pure, the action is very moderate, and requires the assistance of heat. The solution is of a rich green colour, and by evaporation affords rhomboidal crystals, which, according to Bergman, are deliquescent, and by long exposure to a warm air lose their acid. It is partially decomposed by heat.

Muriatic acid acts even more feebly than sulphuric acid on nickel, so that the best mode of removing any crust from the surface of nickel, is to boil it in this acid, which dissolves scarcely any of it: it dissolves its oxide, however: the solution is green, and by evaporation affords crystals, the figure of which is not easily determined, and which are deliquescent.

Nitro-muriatic acid dissolves nickel with facility.

Phosphoric acid not only does not act on nickel, but, according to Bergman, scarcely dissolves any of its oxide, the solution affording no crystals, and being scarcely green. The Fluoric acid combines with the oxide, and forms with it a salt, which can be obtained in crystals of a pale green. The Boracic acid does not immediately combine with it; but the combination may be effected by the exertion of a

double attraction. Carbonic acid may be combined with the oxide of nickel by a similar method—adding to the solution of nitrate of nickel a solution of carbonate of potassa; a precipitate of carbonate of nickel is formed of a rich apple-green colour; 2927 parts are obtained, according to Richter, from 1000 parts of nickel. When exposed to heat, its colour changes to a dark grey, with scarcely any green tinge, and with a considerable loss of weight, being reduced by a red heat to 1285 parts: if urged by a strong heat, it approaches more and more to the metallic state, and the small grains are at length attracted by the magnet*.

The salts of nickel are decomposed by the alkalis, and the oxide, more or less free from the acid, is thrown down. If the alkalis are added in excess, they re-dissolve it; and with ammonia in particular, soluble triple salts are formed. Potassa and soda dissolve even a small quantity of its pure oxide: ammonia dissolves it in much larger quantity. From the experiments of Thenard, it appears, that it is the green oxide which is soluble in ammonia, and that the black oxide, in being acted on by that alkali, is reduced to the state of green oxide; its excess of oxygen combining with the hydrogen of part of the ammonia, and nitrogen gas being disengaged†. The solution of the oxide of nickel in ammonia is of a rich blue colour, similar to that of the oxide of copper in ammonia; but what peculiarly distinguishes it, is, that it gradually changes to a purple, and lastly to a violet: the violet colour is, by

* Nicholson's Journal, vol. xii. p. 80.

† Philosophical Magazine, vol. xx. p. 67.

the addition of an acid, changed to a green ; but, by the addition of ammonia, the original colour is reproduced. These changes of colour Richter points out as characteristic of pure nickel *. The solution of oxide of nickel in ammonia is decomposed, according to Mr Phillips, by the addition of soda or potassa ; and he has pointed out this as affording a certain and easy method of obtaining, what is otherwise very difficult, nickel free from cobalt ; the oxide of the latter, when dissolved in ammonia, being very slowly and sparingly precipitated by potassa, while that of the former is precipitated immediately and largely †. He ascribes these decompositions to the two alkalis combining, and thus weakening the affinity of either to the metallic oxide.

Nickel combines with sulphur by fusion. The compound has a yellow colour, with some brilliancy. It is brittle and hard, and burns when strongly heated in contact with the air. Nickel is also dissolved by the alkaline sulphurets.

With phosphorus, nickel unites, either by projecting the phosphorus on the nickel at a high temperature, or by heating together phosphoric acid and nickel with a little charcoal. The nickel increases in weight one-fifth. The compound is of a white colour, with metallic lustre, and appears composed of a congeries of prisms.

Nickel forms alloys with a number of the metals ; but our knowledge of these combinations is very imperfect. Bergman only has given some slight notices with regard to them ; and even these cannot be relied on, as he never

* Nicholson's Journal, vol. xii. p. 80.

† Philosophical Magazine, vol. xvi. p. 314.

obtained nickel free from alloy. Nickel, he observes, when impure, does not unite with silver; “but this must be attributed to the cobalt it contains; for when well freed from that metal, it easily unites in equal proportions with the silver, and that without any remarkable diminution either of whiteness or ductility. This mixture, fused with borax, tinges it of an hyacinthine colour. Copper unites more slowly with purified nickel, yielding a red and ductile metallic mass, which tinges borax of a reddish hyacinthine colour. With an equal, or a greater bulk of tin, nothing is produced but a brittle mass; in which respect also nickel differs from cobalt. It could not be amalgamated with mercury by trituration. Purified nickel melts with tin, and forms a brittle compound*.” Nickel, Mr Hatchet found, impaired very much the ductility of gold; but this might be owing to its not being free from arsenic, as, from the ductility of which it is possessed in its pure state, we might conclude *a priori*, that it could scarcely communicate brittleness to gold.

The oxide of nickel can be combined by fusion with the vitrifiable earths, and gives to the glasses they form a hyacinthine colour. It gives a similar colour to borax, and to phosphate of soda.

Nickel has not hitherto been applied to any use.

* Chemical Essays, vol. ii. p. 277.

CHAP. XV.

COBALT.

THE ores of cobalt had been used for a property which they derive from the metal, that of giving a rich blue colour to glass, but the metal itself was unknown until it was obtained by Brandt, a Swedish chemist, in 1732. Bergman afterwards more fully investigated its properties. It is extremely difficult to obtain it entirely free from alloy. In the purest state in which it has been obtained, it is of a white colour, inclining to grey, and, if tarnished, to red : it has a moderate degree of lustre : its fracture is compact and of a fine grain : it is hard and brittle, though at a red heat it has a degree of malleability. Its specific gravity is 7.8.

Cobalt occurs in nature alloyed with other metals, and mineralized by oxygen, and by arsenic acid. Its ores are easily distinguished from all others, by their property of communicating to borax or to glass, when fused with them, a deep blue colour, and by their solution in nitromuriatic acid being a sympathetic ink, lines traced with it on paper not being visible when cold, but becoming visible on exposure to a moderate heat.

On a large scale, cobalt is extracted from its ores only in the state of an oxide, without being reduced to the metallic form, not only as this reduction is difficult, but also as the metal is not applied to any use. The ore is roast-

ed, by which the sulphur and arsenic are expelled, and any fusible metal mixed with it is melted out. The cobalt remains in the state of an impure oxide, named Zaffre. The zaffre of commerce is always mixed with siliceous earth; hence, if exposed to a strong heat, it vitrifies: a glass of a dark-blue colour is thus formed, named Smalt, which is used on account of its colour in various arts.

It is from the zaffre of commerce that the chemist obtains cobalt: to obtain it pure, however, is extremely difficult. The common process is to mix the zaffre with three times its weight of black flux, a small quantity of oil, and a little sea-salt; and expose the mixture in a crucible to a strong white heat for some hours. A metallic button is thus obtained, on cooling, at the bottom of the crucible; but the cobalt thus procured is generally alloyed with arsenic and nickel, and sometimes with other metals, particularly iron. Processes have been given by different chemists to obtain it pure, as by Lampadius*, Tassaert†, Trommsdorff‡, Bucholz§, and Richter||. That by Trommsdorff may be selected. “Four parts of zaffre well pulverized are to be mixed carefully with one part of nitre, and half a part of charcoal in powder: this mixture is to be projected in small quantities into a red hot crucible, and this operation repeated three times, adding each time to the residue new portions of the nitre and the charcoal.

* Annales de Chimie, tom. xxvi. p. 89.

† Ibid. tom. xxviii. p. 92.

‡ Nicholson's Journal, vol. xii. p. 258.

§ Philosophical Magazine, vol. xxiii. p. 193.

|| Annales de Chimie, tom. liii. p. 107.

The mass resulting from these detonations ought to be mixed with one part of black flux, and exposed during an hour in a crucible to a red heat. The whole is then to be left to cool; the metallic cobalt is to be separated, pulverized, mixed with three times its weight of nitre, and the mixture detonated with the precautions above mentioned. The iron contained in the cobalt will thus become strongly oxidated, and the arsenic acidified combines with the potash: The mass pulverized is to be lixiviated many times, and repeatedly filtered; and thus the arseniate of potash formed will be separated from the insoluble residue that contains the cobalt. This residue is then to be treated with nitric acid, which dissolves the cobalt without attacking the iron which is found oxidated to its *maximum* of oxidation. The solution is then to be evaporated to dryness, the residue redissolved in nitrous acid, and the liquor filtered, to separate the last portions of the oxide of iron, which might have escaped in the first operation. All that remains to be done after this, is to decompose the nitrate of cobalt by potash, to wash the precipitate, and to effect its reduction by means of heat*." This process is perhaps defective, if nickel be present; but the oxides of nickel and cobalt may be separated, either according to the method of Thenard or that of Phillips, as stated under the history of nickel.

Cobalt, when obtained pure, appears, as well as nickel, to be possessed of magnetic power. Gren remarked, that the purest cobalt is not only attracted by the magnet, but that, according to the experiments of Wenzel, it is capable

* Nicholson's Journal, vol. xii. p. 258.

itself of acting as a magnet. This has been confirmed by Tassaert, who found, that cobalt which had been subjected to processes by which any iron must have been abstracted, and which shewed no trace of that metal, by tests by which a very minute portion of iron intentionally added to it was discovered, was as much attracted by the magnet as iron *. It is probable that this property will be destroyed in it, as well as in iron and nickel, by arsenic.

Cobalt is very infusible : in the heat of a wind-furnace, it can, however, be brought into perfect fusion. Its melting point has been estimated by Guyton at 130° of Wedgwood. By slow cooling, it is even obtained in imperfect prismatic crystals.

When heated strongly in contact with the air, it suffers oxidizement : its oxide is of a blue colour, and as the heat is continued deepens, and at length appears perfectly black. The precipitate which is thrown down from the saline combinations of cobalt by the alkalis, is of a blue colour, and has been regarded by Thenard, in his memoir on cobalt †, as the metal in the first degree of oxidizement ; but it is probably a sub-salt. It dissolves in acids without effervescence. By exposure to the air, it appears to absorb a portion of oxygen : it assumes an olive colour, and, when dissolved in muriatic acid, with the assistance of heat, forms oxymuriatic acid gas. When dried, by exposing it to heat in contact with the air, it acquires a brown colour, which deepens until it become black ; and in this change, according to Thenard, it ab-

* Annales de Chimie, tom. xxviii. p. 102.

† Ibid. tom. xlii. p. 210.

sorbs still more oxygen, as, when dissolved in muriatic acid, it forms a large quantity of oxymuriatic acid gas. Cobalt has been said to combine, when at the maximum of oxidizement, with 0.40 of oxygen. According to Proust, the oxide at the maximum of oxidation contains 0.26 of oxygen, that at the minimum 19 *. Some chemists supposed, that by saturation with oxygen, it is even brought to the state of an acid; but this cobaltic acid, the existence of which was announced by Brugnatelli †, has been proved by the experiments of Darracq ‡, and of Bucholz ||, to be arsenic acid, united with a small proportion of oxide of cobalt.

A number of the acids oxidize cobalt, and combine with its oxide.

The concentrated sulphuric acid scarcely acts on it in the cold, but, when boiled on the metal, sulphurous acid gas is disengaged, and a saline matter is obtained, which, when lixiviated, forms a solution of sulphate of cobalt. This, when concentrated, is of a reddish colour: when green, it denotes the presence of nickel. By evaporation crystals are obtained, acicular, or rhomboidal tetraedral prisms bevelled on the extremities. These are of a reddish colour. This salt is decomposed by heat, and, when urged by a strong fire, affords a black oxide.

Nitric acid is decomposed by cobalt, and the metal is oxidized and dissolved. The solution is of a red colour, and by gentle evaporation affords minute prismatic crys-

* Philosophical Magazine, vol. xxx. p. 341.

† Ibid. vol. vi. p. 227.

‡ Ibid. vol. xii. p. 49.

|| Ibid. vol. xviii. p. 97.

tals of the same colour, which are deliquescent and decomposed by heat.

Muriatic acid does not act on cobalt but with the assistance of heat; a small portion of the metal is dissolved: the oxide is dissolved more readily: this solution, like that of the preceding salts, is of a reddish colour, and by slow evaporation affords needle-like crystals, which are deliquescent. A similar solution is obtained by the action of nitro-muriatic acid on cobalt, or on zaffre. The solution of muriate of cobalt, according to Proust, is blue, and it is only when the oxide is in the state of what he names Hydrate, or combined with water, that it is red.

The solution of muriate of cobalt affords a celebrated sympathetic ink. When much diluted, if letters are traced with it on paper, and allowed to dry, they are invisible; but when the paper is exposed to a moderate heat they appear of a lively green: they disappear again when cold; and the experiment may be repeated for any number of times, taking care only to avoid too strong a heat, by which they are rendered permanent.

The cause of this phenomenon has been ascribed to the muriate of cobalt fixed upon the paper, attracting, when cold, moisture from the atmosphere, by which it is as it were dissolved and rendered invisible: when heated, this moisture is evaporated, and the green colour of the salt appears. This explanation appears to be confirmed by the fact, that the characters are rendered visible by confining the paper in a vessel with quicklime, or sulphuric acid, either of which attracts humidity powerfully. The green colour cannot, however, be ascribed entirely to the concentration, but is owing to the temperature; for the

solution itself becomes green when moderately heated in a close phial, and loses this green colour as it cools; nor is it easy to explain how the temperature does produce this change of colour. Mr Hatchet has suggested, that it may operate by causing “a temporary difference to take place in the proportions of oxygen existing in the acid menstruum and the oxide *,” and it is not impossible that a high temperature may enable the metal to attract a small portion of oxygen from the acid, which the acid may abstract from the oxide when the temperature falls. Proust supposes it owing to the heat, subverting the combination of the oxide with water, in consequence of which the blue colour of muriate of cobalt is produced, and this appears green from the intermixture of nickel, which gives a yellow colour †.

A blue or purple sympathetic ink is said to be formed, by boiling one part of pure oxide of cobalt in sixteen parts of distilled vinegar, and evaporating the solution to one-fourth of the whole. The fluid is filtered, and is again evaporated to one-half. Muriate of soda, to the amount of one-fourth of the cobalt, is dissolved in it, and the solution strained. And a red sympathetic ink, it is affirmed, may be made by dissolving pure oxide of cobalt in pure acetic acid, and diluting the solution with water.

The actions of the other acids on cobalt have not been minutely examined. Phosphoric acid dissolves its oxide, and forms a red-coloured solution, which becomes turbid as the solution is saturated, probably from the sparing so-

* Philosophical Transactions, 1796, p. 333.

† Philosophical Magazine, vol. xxx. p. 342.

lubility of the salt. Fluoric acid dissolves the oxide, forming, according to Scheele, a gelatinous solution; which, according to Fourcroy, yields crystals by evaporation. Boracic acid forms, with oxide of cobalt, a compound of sparing solubility, which is precipitated when a solution of borate of soda is added to a solution of nitrate of cobalt. By a similar process, the compound of carbonic acid, with oxide of cobalt, is formed, which is likewise insoluble.

The solutions of the salts of cobalt are decomposed by the alkalis, and precipitates thrown down of a red tinge, or, according to Thenard, of a blue colour, if the cobalt has been pure. By an excess of alkali, these are re-dissolved. This is more particularly the case with ammonia: the solution is of a deep-red colour: if there is an excess of ammonia, it is decomposed very sparingly by potassa, and, even when the excess is evaporated, the decomposition is slow and imperfect: the solution, on the addition of the potassa, changes from red to pink, then to brown, and at length deposits a quantity of brown oxide of cobalt *. According to Thenard's experiments †, it is the blue oxide only that is soluble in ammonia; the black, or that at the higher degree of oxidizement, being not sensibly dissolved. The ternary salt, obtained by adding to nitrate of cobalt, ammonia in quantity sufficient to re-dissolve the precipitate that is at first formed, may be obtained by evaporation in small cubes of a red colour. These crystals are permanent in the air, and are decomposed by heat ‡.

* Philosophical Magazine, vol. xvi. p. 314.

† Ibid. vol. xx. p. 66.

‡ Annales de Chimie, tom. xlii. p. 215.

Cobalt does not combine with sulphur by fusion, but it combines with the alkaline sulphurets; the compound being of a white or yellowish colour, and a crystalline texture. Hydro-sulphuret of potassa throws down a black precipitate from the solution of nitrate or muriate of cobalt, which, by the addition of an excess of the hydro-sulphuret, is re-dissolved*.

When small pieces of phosphorus are projected on cobalt ignited in a crucible, the cobalt is fused, from combining with the phosphorus, and forming a compound more fusible than the metal: it thus absorbs about one-fifteenth of its weight. A similar compound is obtained by fusing together cobalt, concrete phosphoric acid, and a little charcoal. The phosphuret is of a white colour, with metallic lustre, which is impaired on exposure to the air: it is brittle, and of a striated fracture. Urged by the flame of the blowpipe, the phosphorus is burnt out, and a blue oxide of cobalt remains, forming, with a portion of the phosphoric acid, a vitreous globule.

Cobalt combines with many of the metals. Its alloys are generally brittle, and none of them has been applied to any use; nor have they been much examined. That with gold, in which the cobalt is only one-fifteenth of the mass, was found by Mr Hatchet to be of a dull yellow colour, and very brittle: it was brittle even when the proportion of cobalt amounted only to $\frac{1}{65}$. The combination with silver is not easily effected, and appears to take place to a certain extent only, in consequence of the affinity of the one metal to the other being aided by

* *Annales de Chimie*, tom. xxviii. p. 104.

its quantity. Hence, when they are fused together, on cooling, the upper part of the mass is principally cobalt, which, being whiter than usual, appears to have a little silver combined, while the other is principally silver, which, from being brittle and of a grey colour, appears to have a portion of cobalt in combination. The relation of cobalt to platina is not known. It cannot be united with quicksilver. With copper it has been said to form an alloy of a white colour, hard and brittle; but this, as indeed many of the observations with regard to the alloys of cobalt, applies only to the metal in its impure state. The affinity of cobalt to iron has been considered as very powerful, from the difficulty of separating them, though the opinion with regard to this difficulty appears to have arisen from the supposition that the magnetic quality of cobalt depends on iron. Iron and cobalt, however, combine together, forming an alloy of a close grain, and very hard. It had been supposed, that cobalt does not unite with lead; but, from the experiments of Gmelin, it appears, that they can be combined, and in different proportions, by exposure in a covered crucible to the heat of a forge. Equal parts formed an alloy, having more resemblance to cobalt than to lead, brittle, and of the specific gravity 8.12. With two parts, and even with four parts of lead, and one of cobalt, alloys were formed, brittle, and harder than lead: with six parts of lead it was more malleable: with eight parts its malleability was equal to that of lead, and its hardness greater: its specific gravity was 9.78 *. The

* *Annales de Chimie*, tom. xix. p. 359.

alloy with tin is said to be of a close grain, and of a violet colour. Cobalt does not combine with zinc. With nickel it is often naturally united: the alloy that may be artificially formed has not been examined.

The principal, or indeed the sole use of cobalt, is to communicate a blue colour to glass, enamel, and porcelain. For this purpose it is used in the state of oxide.

CHAP. XVI.

MANGANESE.

THE ores of manganese had, from their external characters, been confounded with those of iron. Bergman and Scheele first regarded the native oxide of manganese as containing a peculiar metal, and this metal was first obtained by another Swedish chemist, Gahn. At rather an earlier period, it appears that Dr Irvine of Glasgow had formed the same conclusion with regard to manganese, and had examined some of its properties*. The name Manganese, which was formerly given to the native oxide, is now appropriated to the metal.

Manganese, when obtained in its metallic form, is of a white colour, with a shade of grey, and with moderate lustre. Its texture is granular: its hardness about equal to that of iron. It appears to be possessed of neither ductility nor malleability. Its specific gravity is 6.850. It is generally weakly magnetic, probably from an alloy of iron.

* Preface to Dr Irvine's Chemical Essays.

There are two species of manganese ores; one in which it is mineralized by oxygen, forming the black oxide; the other in which the oxide is combined with carbonic acid, forming the red ore; though both also contain other ingredients in variable quantities, particularly oxide of iron and silex. These, especially the black, occur in many countries. In England, there are mines in Devonshire, Somersetshire, and Derbyshire: in Scotland, a mine has been lately discovered in Aberdeenshire. The carbonate, or red ore, is found principally in Transylvania. The oxide occurs in small quantity in a number of other minerals, and exists also in the vegetable kingdom, as it is to be found generally in the ashes of plants.

The oxide of manganese in the state in which nature affords it, is used in several arts; but the metal itself is applied to no useful purpose, and is therefore never extracted from its ore on a large scale. The reduction of it even in small quantity is very difficult, partly from its strong attraction to oxygen, and partly from its great infusibility; nor is it ever obtained but in small metallic globules. The process which has been generally followed, is to select a pure oxide of manganese, reduce it to powder, make it into a ball with a little oil, and expose it imbedded in charcoal, in a covered crucible, to a very intense heat gradually raised. To obtain it with more certainty free from iron, it may be proper, instead of operating on the native oxide, to dissolve this in nitric acid, adding a little sugar, which, as is afterwards to be stated, promotes the solution: this solution is to be decomposed by carbonate of soda: the white precipitate that is thrown down, is carbonate of manganese, which may then be

reduced according to the preceding process. Other methods more complicated are given by Mr Kirwan, by which the iron may be completely abstracted *.

It has been observed, that the globules of metallic manganese, when exposed to the air, split, fall to pieces, and at length are converted to a black powder. Yet other specimens are also obtained, which are not liable to this change, preserving their metallic appearance unaltered. This difference Mr Kirwan supposed owing to the former containing carbon, which absorbs oxygen, and subverts the cohesion of the metal †.

The melting point of manganese can scarcely be estimated with precision. It is supposed by Guyton to be at least 160° of Wedgwood.

Exposed to heat in contact with the air, it passes rapidly through different stages of oxidizement, assumes at first a grey colour, which passes to a yellow, red, and brown, and at length becomes perfectly black. By precipitation from some of its saline combinations, it is obtained also in the state of an oxide, white, or at least of a yellowish colour approaching to white. The black oxide is evidently the metal at the *maximum* of oxidizement, the white is the one at the *minimum*. In conformity to the opinion which was held by chemists, with regard to two determinate degrees of oxidizement in every metal, the others were regarded as mere mixtures of these : but there is no foundation for this view ; and the different colours which the manganese assumes, denote the various

* Elements of Mineralogy, vol. ii. p. 460.

† Ibid. vol. ii. p. 288.

degrees of oxidizement of which it is susceptible, and which, between the *maximum* and *minimum*, are probably indefinite. According to Bergman, the white oxide consists of 80 of manganese, and 20 of oxygen: the black oxide is stated by Fourcroy, to be composed of 60 of manganese, and 40 of oxygen.

When manganese is in the lower degrees of oxidizement, such as it is when it is precipitated from its saline combinations, it quickly absorbs oxygen on exposure to the air, especially when it is in a humid state: its colour deepens, and this continues to proceed, until it is saturated with oxygen, and has become perfectly black. The black oxide, exposed to the heat of ignition, yields oxygen gas, and this in proportion as the heat is raised. No heat, however, is sufficient to reduce it to the state of the lighter-coloured oxide: it can be brought no farther than the brown; the affinity of the metal to the oxygen becoming stronger as its quantity is relatively increased, in other words, as more of the oxygen is expelled, is at length sufficient to counteract the effect of the high temperature in communicating elasticity to the oxygen, and puts a stop to the decomposition. By exposure to air, this brown oxide again deepens in its colour. The oxygen expelled from the black oxide of manganese has been supposed to be less pure than that from some other substances, especially from the hyper-oxymuriate of potassa; but when care is taken to select the oxide, it is sufficiently pure for the greater number of experimental purposes.

The oxides of manganese are reduced by the operation of carbonaceous matter at a high temperature.

The actions of the acids on metallic manganese have

been little examined, as it is difficult to obtain it in this state, and as it must be oxidized in passing into any saline combination; so that such combinations may equally be obtained by employing the oxidized manganese. In its metallic state, it is acted on by sulphuric acid, especially when the acid is diluted, hydrogen gas being disengaged, from the decomposition of the water; and the metal being oxidized and dissolved: a quantity of a black matter is left undissolved, which has been regarded as carburet of iron. Nitric acid dissolves it, with effervescence from the disengagement of nitric oxide gas. Muriatic acid likewise dissolves it, hydrogen gas being evolved. Thrown into oxymuriatic acid gas, it is inflamed.

The relations of the oxides of manganese to acids have been more examined, particularly by Bergman*: and they present some important theoretical results. It appears that the black oxide is in too high a state of oxidizement to be capable of combining with the acids: it must be previously partially de-oxidized, and this affords the explanation of the results it presents with the different acids.

Thus, when sulphuric acid is poured on the black oxide, and a moderate heat applied to favour their mutual action, the acid and the oxide do not immediately combine, but the oxide parts with a quantity of its oxygen, which assumes the elastic form, and, being thus reduced in its oxidizement, enters into combination. The compound is soluble in water, and forms a solution of a red colour, containing an excess of acid, which may be separated by reducing the salt to a solid state by evaporation,

* Chemical Essays, vol. ii. p. 211.

and applying heat. On re-dissolving it, a solution is formed, which Bergman found to be not easily crystallizable, as, on evaporation, it becomes gelatinous, with a few crystals interspersed. It is deliquescent. The alkalis throw down from it a precipitate of a reddish-yellow colour. Though, in this combination, the metal is less oxidized than it is when in the state of the black oxide, it is not reduced to the *minimum* of oxidizement, but is in an intermediate state. This appears from its colour, and from the colour of the precipitate it affords, compared with that of the solution of the metal itself in sulphuric acid. This is colourless; and, on evaporation, affords colourless crystals, of a rhomboidal form: decomposed by the alkalis, it affords a white precipitate. A similar solution is formed, by adding the white oxide of manganese to diluted sulphuric acid; or by digesting the black oxide with sulphuric acid, and a small quantity of sugar, the carbonaceous matter of which de-oxidizes the salt as it is formed, and reduces it to this state of the sulphate at the minimum of oxidizement. Sulphurous acid, in acting on the black oxide, appears to form a similar salt, as Scheele observed.

Nitric acid, poured on black oxide of manganese, does not dissolve it, from the same cause that the sulphuric does not,—the metal being in too high a state of oxidizement. But the nitrous acid, especially when highly fuming, is capable of acting upon it; the nitric oxide which this contains, abstracting part of the oxygen of the oxide, and thus rendering it soluble in nitric acid. Hence, as Scheele observed, any addition which can have the same effect, renders the nitric acid capable of acting on the

black oxide, as the addition of a little sugar or alcohol, or, what is an elegant experiment, exposing the acid to the rays of the sun, which we know converts it into nitrous. In all these cases, the excess of oxygen is abstracted from the black oxide, and it thus becomes capable of combining with the nitric acid. A similar solution is formed, by adding the white oxide to the nitric acid. In these combinations, the metal appears to be always at the minimum of oxidizement: the solution is colourless, and, when decomposed by the alkalis, affords a white precipitate. The nitrate of manganese does not crystallize.

Muriatic acid is capable of acting on the black oxide of manganese, when aided by a moderate heat, which is owing to its power of combining with oxygen. Hence, in this solution, equally as in the action of the other acids, the oxide is reduced in its degree of oxidizement, a portion of the muriatic acid is converted into the oxy-muriatic acid, and the remaining acid combines with the oxide thus changed. It is in this way, indeed, that oxy-muriatic acid is generally formed; and it was in examining the action of muriatic acid on the native black oxide of manganese, that Scheele discovered that acid. The white oxide dissolves readily in muriatic acid, forming a solution similar to that obtained by the preceding process. By evaporation of the muriate of manganese, a soft deliquescent mass is obtained. It appears that manganese unites most readily with muriatic acid, when at a low degree of oxidizement; yet a combination may be effected between them, when the metal is more highly oxidized; for when muriatic acid is allowed to remain with the black oxide, without applying heat, a portion of the

oxide is dissolved, and the solution has a reddish colour. It has always an excess of acid, and, by dilution with water, is partially decomposed.

Phosphoric acid does not act on manganese, but combines with its oxides: the combination being effected by adding a solution of a neutral phosphate to a solution of nitrate or muriate of manganese. The phosphate of manganese being insoluble, is precipitated. By a similar process, the fluuate and the borate of manganese, which are likewise insoluble, and have been little examined, are formed. Carbonic acid, in solution in water, acts weakly on metallic manganese, dissolving a small portion of it, as it does also of the oxide; the solution gradually depositing a pellicle of oxide, on exposure to the air, from the escape of the carbonic acid. The neutral carbonate, of a white colour, is obtained by adding a solution of carbonate of potassa or soda to a solution of nitrate of manganese.

The salts of manganese are decomposed by the alkalis, which throw down precipitates of a yellow or reddish colour. None of them are decomposed by any of the other metals,—a proof, to a certain extent at least, of the strong affinity of manganese to oxygen.

The fixed alkalis, in the dry way, exert a considerable action on oxidized manganese. When the black oxide is exposed to heat with twice its weight of dry soda or potassa, a compound is formed of a dark green colour, which is soluble in water. During its solution, this substance exhibits rapid changes of colour; and hence it has received the fanciful name of the Mineral Chameleon. When a little of it is dropt into a large quantity of wa-

ter, the solution is of a beautiful green colour, but in a few moments it changes to a purple, and then to red. Or if upon a little of it a quantity of water is poured, the solution is of a deep green; but, in diluting it with more water, it presents the same changes of colour. In a few hours it becomes colourless, a reddish precipitate being deposited: Or it is at once rendered colourless, without any precipitation, by a few drops of nitric acid. These changes of colour are probably owing to successive but rapid changes in the degree of oxidizement, and may depend, in part at least, on the oxygen which water holds loosely dissolved. The compound, to exhibit these phenomena, is best prepared by exposing to a red heat, in a covered crucible, one part of the black oxide with three parts of nitre; the acid of the nitre being decomposed, and serving, by the oxygen its decomposition affords, to keep the metal at the maximum of oxidizement, in which state the alkali of the nitre combines with it.

Ammonia passed over oxide of manganese heated to redness, is decomposed; its hydrogen being attracted by the oxygen of the oxide, while its nitrogen combines with another portion of this oxygen, and forms nitric oxide. It has not been ascertained if ammonia dissolves oxide of manganese in the humid way.

Oxide of manganese combines with some of the earths, and with their vitrifiable compounds, and forms coloured glasses. The tinge it communicates is violet, and it is sometimes used in the formation of the pastes to imitate the gems. It communicates a similar colour to borax, phosphate of soda, and other vitrifiable salts; the colours being varied, according to the degree of oxidizement.

Manganese has not been combined with sulphur. Bergman could not effect their combination. Eight parts of oxide of manganese, he observes, by gentle heat in a retort, take up three of sulphur, and produce a yellowish-green mass, which is acted on by acids; the oxide being dissolved with effervescence, and with an odour of sulphuretted hydrogen.

Pelletier combined phosphorus with manganese, by heating equal parts of phosphoric acid and manganese with a little charcoal; or by projecting phosphorus on manganese, heated to ignition. The compound is of a white colour, has metallic lustre, is of a granular texture, brittle, not altered on exposure to the air, but decomposed by heat: it is more fusible than the metal.

Manganese, from its great infusibility, is not easily combined with the other metals; hence its alloys have been little examined. By exposing gold to a very strong heat with black oxide of manganese, and a little oil, an alloy is formed of a pale yellow colour, with a shade of grey, of considerable lustre, very hard, and somewhat ductile: it is decomposed by heat; the manganese being oxidized. Manganese does not unite with silver or with quicksilver: with copper it forms an alloy which is ductile, and of a red colour. To iron it has a considerable affinity: it is generally combined with it in nature, and it is difficult to separate them. When combined artificially, the iron receives a white colour, and is rendered brittle. In steel, manganese is supposed frequently to exist united with iron and carbon. It does not unite, according to Gmelin, with lead. With tin, according to

Bergman, it unites very easily, but not with zinc, at least not without much difficulty.

Manganese itself is not used, but its native black oxide is applied to several purposes. It is the substance from which oxygen can be most economically obtained; and from its power of affording oxygen, large quantities of it are consumed in the formation of the oxymuriatic acid employed in the art of bleaching. It has long been used in the art of glass making; a small quantity of it being added to remove the green colour, which is derived from the oxide of iron always contained in greater or less quantity in the materials from which glass is manufactured; the iron, by its action, being raised to a higher state of oxidation, the manganese being partially deoxidized, and neither of the oxides in these states communicating colour to the glass. It serves also to consume any carbonaceous matter in the materials of the glass. In a large quantity it is used in the composition of ornamental glass, to give a purple colour. It is also employed to give a black colour to earthen ware, a quantity of it being mixed with the composition before it is baked.

CHAP. XIV.

ARSENIC.

THE name Arsenic was in use among the ancients, and appears to have been applied to the native combinations of the metal, which has now received that name, with sulphur. Avicenna mentions white arsenic;

and this substance, sublimed in the roasting of certain metallic ores, was known to the alchemists. Lemery and Schroder first described processess by which metallic arsenic may be obtained from it. Brandt first examined the properties of this metal with accuracy, and the investigation was prosecuted by Macquer, Bergman, and Scheele.

Arsenic in its metallic state is of a bluish-grey colour, with considerable lustre, but which is very liable to tarnish, and become black from exposure to the air. Its texture is foliated, or rather broad striated : it is not very hard, and is extremely brittle, so as to fall into fragments from a slight blow. Its specific gravity is stated by Bergman at 8.310 ; by Brisson at 5.763. In its solid state, it is inodorous ; but when volatilized, its vapour has a strong and peculiar smell, resembling the smell of garlic. It is known to be, in its oxidized state, the most violent of all the mineral poisons.

Arsenic occurs native alloyed with iron, and sometimes small portions of other metals ; mineralized by oxygen, by sulphur, with sometimes the addition of other metals, and in the state of acid combined with lime. Its most common ores are the sulphurets, the yellow being named Orpiment, the Red Realgar.

As metallic arsenic is applied to no use, it is not extracted from its ores, but is obtained always in the state of the white oxide. The greater part of this is procured in roasting other metallic ores, particularly those of cobalt, in which arsenic is contained. The roasting is performed in furnaces with long flues, in which the vapours of oxidized arsenic are condensed, and the oxide is purified by sublimation. Sometimes also it is obtained

by sublimation from arsenical pyrites. It is this white oxide that is known in common language by the name of Arsenic. The process is carried on in Saxony and Bohemia on a large scale*.

To obtain the arsenic in its metallic state, the common process is to mix the white oxide with twice or thrice its weight of black flux, and expose the mixture to heat in a glass tube or retort; or if a larger quantity be operated on, in a crucible, to which another is luted so as to be airtight. On raising the heat to ignition, the oxide is reduced, and the metal sublimed, and, when the apparatus is cold, is obtained in the form of a brilliant crust, which has a crystalline form, and to which there frequently adhere regular crystals, prismatic or octaedral.

Arsenic is so volatile that its fusing point can scarcely be ascertained: it passes into vapour when heated, without becoming previously fluid. Its vaporific point is, according to Bergman, about 388 of Fahrenheit †.

This metal is very susceptible of oxidizement: it suffers this change even from exposure to the atmospheric air, becoming black, and at length falling to powder. When heated, the oxidizement proceeds still more rapidly: at a temperature about that at which it is volatilized, it forms a white smoke, consisting of the oxide in vapour, and distinguished by the peculiar garlic smell. When the heat is raised a little higher, the arsenic burns with a dull blue flame, and with the production of the same oxide.

This oxide is possessed of very peculiar properties. In-

* Journal de Physique, tom. li. p. 44.

† Chemical Essays, vol. ii. p. 282.

stead of being insipid, as the greater number of metallic oxides are, it has an acrid taste, and is corrosive: it is soluble in water, requiring not more than 80 parts of cold water, or 15 parts of boiling water: the latter solution deposits, on cooling, crystals in the form of tetraedral prisms, or octaedrons. It reddens the infusion of litmus, and combines with the alkalis. From these properties, Fourcroy has proposed to consider it rather as an acid than as an oxide, and has named it the Arsenious Acid, an arrangement for which there is undoubtedly some foundation. Yet, as Berthollet has remarked, this substance is on the whole more analogous to the highly oxidized oxides: it does not exert a greater action on the alkalis than they do; and to this it may be added, that it combines with the acids, and neutralizes the acid properties. This oxide is volatile, but less so than the metal: it requires, according to Bergman, a temperature of about 415° of Fahrenheit to pass into vapour. By sublimation it is obtained in the form of a dense solid cake, the form in which the white oxide of arsenic is often met with. Its specific gravity is 5.000; that of the unsublimed oxide is 3.706. According to Proust, this oxide consists of 75.2 of arsenic, and 24.8 of oxygen.

Arsenic is capable of passing to a higher degree of oxidizement, and it then acquires all the properties of an acid. This was discovered by Scheele. The acid may be obtained by distilling nitric acid from the white oxide of arsenic, the acid communicating oxygen to the acid; but the process is slow and imperfect. It succeeds better when the oxide is previously dissolved in muriatic acid, as the nitric acid can act with more energy on the oxide

in this state of division. On this is founded the process of Scheele. Two parts of the white oxide are dissolved in seven parts of muriatic acid, with the assistance of heat, and there are added to this solution, in a retort, three parts and a half of nitric acid : the nitric acid affords oxygen to the oxide ; and much nitric oxide gas is disengaged. The distillation is continued until this ceases : one part of oxide of arsenic is again added, and a moderate heat applied until it is dissolved. One part and a half of nitric acid is lastly poured on the solution, and the whole is distilled to dryness, the fire being raised towards the end of the distillation, so as to bring the bottom of the retort to a red heat. The solid arsenic acid is thus obtained *. According to Proust, the oxide of arsenic, in passing to this state, acquires nearly one-seventh of increase of weight. The acid consists, according to his experiments, of 65.4 of arsenic, 34.6 of oxygen ; or in 100 parts 13.5 more oxygen than the white oxide. Thenard states the proportions from synthetic experiments at 64 of arsenic, and 36 of oxygen †, with which the estimate of Bucholz exactly agrees.

The acid powers of this substance are altogether unequivocal. It is abundantly soluble in water, requiring not more than six parts for its solution at the temperature of 60°, and not more than two parts at 212° : its taste is sour : it reddens instantly the vegetable colours, neutralizes completely the alkaline properties, and combines with the metallic oxides and earths. Its solution, when concentrat-

* Chemical Essays, p. 143.

† Philosophical Magazine, vol. xx. p. 66.

ed, is of an oily consistence, and by evaporation affords small irregular crystals. When the water is evaporated, it forms a solid mass of a white colour, which, by raising the heat to ignition, is melted, and forms a translucent glass. It is not volatile,—a proof of the great condensation the oxygen has experienced in the combination, since, not only is the compound inferior in volatility to the mean volatility of its constituent principles, but is even less volatile than the one which is of greatest fixity.

By strong heat this acid is decomposed, part of its oxygen is expelled, and it is reduced to the state of the white oxide. It is also decomposed by inflammable bodies, which abstract its oxygen. The mere transmission of a current of hydrogen gas through its concentrated solution, appears sufficient, from the experiments of Pelletier, to reduce it to the metallic state *. Sulphur and charcoal at a high temperature equally decompose it, as do a number of the metals.

Both the oxide and the acid of arsenic are capable of forming a number of combinations with the other chemical agents. Those of the oxide may first be considered.

It unites with the different acids, though it is difficult to obtain these compounds neutral. The same combinations are in general produced by the action of the acids on metallic arsenic; the acid first causing the oxidizement of the metal, and then combining with the oxide.

Sulphuric acid does not act on arsenic in the cold, but, boiled on it, the metal is oxidized, and this oxide combines with a part of the acid. The acid, when boiled on the

* *Mémoires de Chimie*, tom. i. p. 21.

oxide, dissolves a portion of it, and deposits, as it cools, crystalline grains less soluble than the oxide itself, and which are decomposed by heat*.

Nitric acid speedily oxidizes metallic arsenic. When diluted, it dissolves the oxide: the compound being very sparingly soluble, is deposited on evaporation. The concentrated acid, in acting on the oxide, communicates still more oxygen to it; and, when distilled from it, converts it, though rather imperfectly, into arsenic acid.

Muriatic acid exerts a very weak action on metallic arsenic, unless it be boiled on it. The metal is then oxidized at the expence of the water, and a quantity of hydrogen gas disengaged of a very foetid odour, which it owes to a portion of arsenic that it holds in solution. The acid dissolves by boiling one-third of its weight of the white oxide; the muriate of arsenic being in a great measure deposited when the solution cools. This salt is sparingly soluble in boiling water: it may be obtained crystallized: it is volatile, being in a close vessel completely sublimed†. The chemists were also accustomed to obtain muriate of arsenic in a concentrated state, by exposing a mixture of corrosive muriate of mercury and of metallic arsenic, or of sulphuret of arsenic, to heat in a retort; the acid, with a portion of the oxygen, being transferred to the arsenic, and the muriate distilling over it, and being condensed, partly in the state of a dense liquid, and partly in a congealed state. Though it appears probable, that in this combination the metal may be in

* Bergman's Essays, vol. ii. p. 96.

† Ibid. p. 296.

a higher state of oxidizement than in the solution obtained by boiling the oxide in muriatic acid, they scarcely differ, according to Bergman, but in concentration. The compound emits acrid vapours: it is decomposed by water: by the action of alkalis, a precipitate is thrown down from it. By spontaneous evaporation, it deposits pellucid crystals, which are sparingly soluble in water.

Oxymuriatic acid acts with energy on metallic arsenic. When fragments of it are projected into the gas, they are inflamed. The liquid acid, digested on the white oxide, converts it into arsenic acid.

The other acids scarcely act on arsenic. Fluoric acid dissolves the oxide, and forms crystalline grains, as does also phosphoric acid. Boracic acid also dissolves the oxide: the compound is soluble in water, and the solution, on evaporation, deposits the borate of arsenic, partly in the state of a powder, partly in slender crystals. Carbonic acid does not dissolve the oxide, at least water impregnated with it does not dissolve more than pure water would do*.

Oxide of arsenic is capable of combining with the alkalis. They unite by fusion. Pure potassa, at the temperature of ignition, unites with twice its weight of the oxide, the volatility of which it completely restrains. Soda can fix three times its weight. The solutions of these alkalis boiled on the oxide, also dissolve a considerable proportion of it: the solution, when concentrated, becomes thick and tenacious, of a brown colour, and emits a disagreeable odour. The oxide is partly, though not

* Bergman's Essays, vol. ii. p. 295-298.

entirely, precipitated by acids. Ammonia also dissolves a portion of the oxide, as does lime-water; and lime, and some of the other earths, combine with it by fusion*.

In these chemical relations, the oxide of arsenic appears nearly equally energetic in its action on acids and on alkalis. When more highly oxidized, however, so as to be in the state of arsenic acid, its action is more powerful on the latter, on the earths, and on the metallic oxides. It forms with them neutral combinations, which are denominated Arseniates.

The Arseniate of Potassa was discovered by Macquer, and was the first of this order of salts that was known; its discovery being prior even to that of the arsenic acid by Scheele. It was obtained by an indirect process. Equal parts of white oxide of arsenic and of nitre were exposed to heat in a retort; the heat being continued until the copious red vapours, which are at first produced, have ceased. On adding to the residual matter hot water, it is dissolved, and, by evaporation, affords large regular crystals; the form of which is a tetraedral prism acuminate by four planes. The theory of the process is evident; the nitric acid of the nitre is decomposed during the distillation: its oxygen transferred to the oxide of arsenic, converts it into arsenic acid, which combines with the potassa of the nitre. It has always an excess of acid. It is fused by heat, but is not decomposed. The neutral salt, which may be formed by the direct combination of the acid and alkali, does not crystallize with so much regularity, and is deliquescent.

* Bergman's Essays, vol. ii. p. 293.

Arseniate of soda is formed by the same indirect process as arseniate of potassa, substituting of course nitrate of soda for nitre. It crystallizes in hexaedral prisms.

The arseniate of ammonia can be formed, according to Bergman, by exposing to heat a mixture of nitrate of ammonia, and of oxide of arsenic ; but as the ammonia is liable to be decomposed, it is better prepared by the direct combination of its constituent principles. It crystallizes in rhomboidal prisms. It is decomposed by heat ; the ammonia being at first expelled, and, towards the end of the process, decomposed.

Arsenic acid forms similar combinations with some of the earths. Its compound with lime is sparingly soluble, but is rendered more soluble by an excess of acid ; and, in this state, crystals are obtained by evaporation of the solution. The salt which it forms with magnesia, is, in like manner, of sparing solubility when neutral, but, with an excess of acid, becomes soluble, and forms a gelatinous mass by evaporation. The arseniate of argil and barytes are likewise nearly insoluble. These salts are not decomposed by heat alone, but, if a small portion of charcoal be added, the acid is decomposed, and oxide of arsenic is sublimed *.

Arsenic acids act on several of the metals, and is capable of combining with the greater number of them when oxidized. These combinations, presenting no results important under any point of view, require to be only briefly noticed ; and, indeed, they have not been

* Scheele's Essays, p. 163.

much examined. We are principally indebted to Scheele for our knowledge of them.

On gold, arsenic acid exerts no action, neither does it occasion any precipitate in the solution of gold. Silver is not acted on by the acid, but the alkaline arseniates decompose nitrate of silver; a complex affinity being exerted, and the arsenic acid combined with the oxide of silver: the compound is, to a certain extent, soluble in water, and is decomposed by heat, oxide of arsenic being sublimed from it. On quicksilver, arsenic acid exerts no action in the humid way, but, when exposed to a high temperature, the acid is in part decomposed, the mercury oxidized, and this, combining with the remaining acid, forms an arseniate of mercury, which, by a farther application of the heat, suffers decomposition. Digested with copper, arsenic acid forms a green solution, and a powder of a bluish-white colour, is precipitated, which is arseniate of copper. By heat it fuses into a glass. This combination, it has already been remarked, exists native, forming a copper ore. Iron is dissolved by arsenic acid, the action being promoted by a moderate heat: the solution, by evaporation, becomes gelatinous: the acid may also be combined with oxide of iron by double affinity. Arseniate of iron is, as well as arseniate of copper, a native production. Lead becomes black when arsenic acid is digested on it; and, when they are exposed together to heat, the acid is in part decomposed, oxide of arsenic is sublimed, and arseniate of lead remains, which may be fused into a white glass. The arsenic acid precipitates oxide of lead from the greater number of its saline combinations, by combining with it, and forming

an insoluble compound; and a similar compound is formed, by mixing any of the salts of lead with any of the soluble arseniates,—a property which affords the best mode of separating arsenic from the other metals. Arseniate of lead, according to Thenard's analysis of it, is composed of 35.5 of arsénic acid, and 64.5 of oxide of lead. Arsénic acid, by digesting on tin, oxidizes and dissolves a portion of it, forming a gelatinous solution, and it produces a precipitate from some of the salts of tin. Zinc is dissolved by it, with effervescence from the disengagement of hydrogen, and a black powder separates, which is arseniate of zinc. When zinc-filings and arsénic acid are heated together, an inflammation and detonation take place, and arsenic and oxide of zinc are volatilized. The solutions of zinc are decomposed by the arseniates. Nickel is dissolved by arsénic acid: the solution has a green colour, and a green powder is precipitated: the acid does not precipitate oxide of nickel from its solutions, but the arseniates produce a precipitate when added to the salts of nickel. The acid, when digested on cobalt, acquires a rose colour; and a precipitate of a similar colour is formed by adding any of the alkaline arseniates to a solution of cobalt. Manganese is dissolved in small quantity by it; and, if heated with the acid in its concrete state, partially de-oxidizes it, and forms oxide of arsenic. Bismuth, by digestion with the liquid acid, is converted into a white powder, and its oxide is also precipitated by it from its solution in other acids. Antimony likewise forms a white powder, by digestion, with arsénic acid; and, if distilled to dryness, an inflammation

takes place as soon as the mass passes into fusion. By arsenic itself, arsenic acid is converted into the white oxide*.

Arsenic is dissolved by hydrogen. Scheele proved, that the gas which is disengaged when zinc is acted on by arsenic acid, is hydrogen, holding a portion of arsenic dissolved, as, when detonated, it deposited a film of metallic arsenic. Proust shewed that it could be procured with more facility, and in greater abundance, by mixing diluted sulphuric acid, zinc, and oxide of arsenic; the hydrogen disengaged, reducing the oxide, and dissolving the arsenic†. Its properties have been more lately examined by Trommsdorff. It has the peculiar garlic odour; is not absorbed by water; does not alter the colour of litmus; is heavier than pure hydrogen, or than sulphuretted hydrogen; its specific gravity being 0.5293. It is decomposed with detonation when kindled with atmospheric air or oxygen: when kindled with the former, it deposits the greater part of the arsenic it holds dissolved, in the metallic state: when detonated with the latter, the temperature being higher, the arsenic, as well as the hydrogen, combines with oxygen, and passes to the state of the white oxide. It is also decomposed by nitric oxide gas, and oxymuriatic acid gas. The latter acts on it readily in the cold: when slowly introduced to it, the arseniated hydrogen gas is diminished in volume, and metallic arsenic deposited, which, if the addition of the oxymuriatic acid gas be continued, is changed into oxide of arsenic. When nitrous acid is poured into a phial con-

* Scheele's Chemical Essays, p. 168.

† Journal de Physique, tom. li. p. 175.

taining it, the gas is kindled with detonation. Sulphuric acid precipitates a metallic film from it; and nitromuriatic acid first precipitates, and then oxidizes the metal. It decomposes, and is decomposed by a number of metallic solutions. It does not combine with the alkalis. According to this chemist, one cubic inch of this gas weighs 0.2435 grains, (French weight); a cubic inch of pure hydrogen weighs 0.0353; whence he infers, that that quantity must contain 0.2082 of arsenic, or that the gas consists of .0353 hydrogen, and .2082 of arsenic by weight, which, however, is scarcely possible from its specific gravity; and the data from which the conclusion is inferred, are imperfect *. Stroy Meyer has added some observations on arseniated hydrogen. He finds it to be most easily produced by digesting an alloy of 15 parts of tin, and 1 of arsenic, with concentrated muriatic acid. The gas disengaged has a very foetid smell, and proves peculiarly fatal to animal life. Though aeriform, it was condensed in part into a liquid, by immersing it into a mixture of snow and muriate of lime. The other properties which he observed in it are nearly the same as those described by Trommsdorff. From its decomposition by nitric acid, he infers the proportions of its principles, which, as he states them, are 10.600 arsenic, and 0.219 hydrogen †.

Arsenic does not combine with carbon. With sulphur it unites easily by fusion, or by sublimation, the compound being of a red or of a yellow colour, according to

* Nicholson's Journal, vol. vi. p. 200.

† Ibid. vol. xix. p. 381.

the proportions. Similar compounds are formed when the oxide is heated with sulphur; a portion of the sulphur attracting the oxygen of the oxide, and forming sulphurous acid gas, which, as Bergman observed, is always disengaged. The alkaline sulphurets likewise dissolve arsenic, but the combination is easily subverted by the action of an acid.

Arsenic combines with phosphorus, by exposing equal parts of them to a moderate heat in a retort. The compound is a shining mass of a black colour, which decomposes by exposure to the air, and burns when projected on burning fuel. A similar combination is obtained by heating phosphorus with oxide of arsenic.

Arsenic combines with the greater number of the metals. It in general very much impairs the ductility of those which are ductile, and renders fusible those which are refractory in the fire: it often also communicates greater hardness and brilliancy: it destroys the magnetism of the metals which are possessed of this property. Several of these alloys have been already noticed.

Gold has its ductility impaired by a very small quantity of arsenic, not exceeding, according to Mr Hatchet's experiments, $\frac{1}{900}$ of the gold; and when the quantity is greater, the alloy is quite brittle, and very fusible: it is of a grey colour, and the arsenic is not easily separated from it. With silver arsenic unites, especially when a little alkali is added, which prevents the volatilization of the arsenic: the alloy is very brittle, and the arsenic can scarcely be altogether expelled from it. Platina it renders much more fusible; and hence, as has been already stated, it is employed in one of the processes by which

that metal is worked, the arsenic being volatilized from the platina by exposure to a very strong heat. It does not easily amalgamate with quicksilver, but, by continued trituration, aided by a moderate heat, the combination may be effected. The amalgam is of a grey colour. With copper it can combine without difficulty, either by fusing them together in a covered vessel, or by exposing to heat copper granulated, or in thin plates, with oxide of arsenic and charcoal powder. The alloy is flexible and malleable, of a white colour, and susceptible of a high polish, but it tarnishes and becomes black on exposure to the air: it is sometimes used instead of pure copper in plating with silver. Iron is rendered brittle and of a white colour by an alloy of arsenic. Lead combines with about one-sixth of its weight of it, and becomes brittle and of a dark colour. Tin in combining with arsenic acquires a very white colour, becomes harder, and at the same time more brittle. Zinc unites with it by being exposed to heat with oxide of arsenic, but the properties of the alloy have not been examined. Nickel exerts a strong attraction to it, as, when they are united, the arsenic is not easily separated. The compound is hard and brittle. It has also a strong affinity to cobalt, as, when naturally combined, which they frequently are, they are separated with much difficulty. Its relation to manganese has not been ascertained.

Arsenic precipitates several of the metals from their solutions, particularly gold, silver, platina, and quicksilver. Its oxide combines also with some of the other metallic oxides. A combination of this kind with oxide of copper, forms a pigment of a fine green colour, discovered by

Scheele, and known by the absurd name of vegetable green. To prepare it, two pounds of sulphate of copper are dissolved in twelve pounds of water, in a copper vessel, placed over the fire. Two pounds of the potashes of commerce, and eleven ounces of white oxide of arsenic in powder, are dissolved in another vessel, in four pounds of water. This solution, strained through linen, is added by small quantities at a time to the former solution, stirring it constantly. A precipitate is deposited of a green colour, which, after being washed with warm water, is to be dried with a moderate heat. It consists of oxides of copper and arsenic, the former being separated by the potash from the sulphate of copper, and uniting in its precipitation with a portion of the latter *.

Arsenic is used in several of the arts. In the state of the white oxide it is used in the manufacture of glass to give it more transparency, and, in a larger quantity, a milky opacity. It is an ingredient in several of the processes of dyeing, and some of its preparations are used as paints. It is sometimes employed in the practice of medicine.

From oxide of arsenic being employed as a poison, it is often of importance, in cases of judicial investigation, to have infallible tests by which it can be recognised. These chemistry is capable of furnishing.

1st, A little of the oxide may be mixed with about twice its weight of black flux, or if this cannot be procured, an equal weight of charcoal powder, and exposed to a low red heat in a glass tube, coated with clay and

* Chemical Essays, p. 253.

sand, and stopt with a plug of clay. The oxide will be reduced, and, the metal being volatilized, will form a brilliant crust on the internal surface of the tube. This may be reserved for other experiments.

2*d*, If a small quantity of the reduced metal in powder, or a little of the white oxide made into a soft paste with the black flux (or if this cannot be procured, with charcoal powder) and oil, be placed between two clean pieces of copper securing them by iron wire twisted round ; after exposure of the pieces to a red heat for ten minutes, they will be found permanently whitened on the surfaces which had been in contact with the arsenic.

3*d*, If a little of the oxide be dissolved in hot water, with three times its weight of carbonate of potassa ; on adding this solution to a warm solution of sulphate of copper, a precipitate of a lively green colour will be formed.

Lastly, a minute quantity of the oxide may be put on a piece of iron and heated : it will evaporate in a white smoke before the iron is red-hot. If, before being exposed to heat, it is made into a paste with oil, it will when evaporating present the peculiar smell resembling that of garlic, which arsenic in vapour has. Or by heating a small piece of the reduced metal, it will be volatilized with the same odour.

Of these tests, those in the last paragraph are the least certain. Other substances, not very different in appearance from oxide of arsenic, may be volatilized when placed on a hot iron ; and though the test of the arsenical odour has been much relied on, there is perhaps some room for fallacy, not only from the difficulty of judging

of it with accuracy, and so as to guard against imagination, but also, as some other metals, particularly antimony, have been supposed in volatilizing to give an odour more feeble indeed, but still somewhat similar *.

Some observations on this subject have lately been made by Dr Bostock, in which the processes are described minutely, and some additional precautions properly recommended †. The first is unquestionably the most decisive ; and the only disadvantage attending it is, that it is not the most delicate, and can be used only when at least more than a grain of oxide of arsenic is operated on. With regard to the second, Dr Bostock remarks, that when plates of copper, with a little charcoal and oil alone, are heated, the copper acquires a white colour from oxidation. When this is rubbed off, it has a light colour resembling brass, and in some parts is of a steel grey. Of this, no doubt, it is necessary to be aware. To render the experiment less doubtful, the copper-pieces should, after the experiments, be rubbed with a little fine sand, and afterwards with a little soft chalk ; the silvery white colour will then be apparent, and is so well marked, unless a very minute quantity of arsenic has been employed, that I can scarcely suppose it liable to any fallacy. The third experiment, Dr Bostock considers as affording the best test. It has the advantage, that it can be employed though no solid arsenic be procured, either on the remaining portion of any liquid that may have been the vehicle of the poison, or on the liquid found in the stomach, diluted

* Brochant *Traité de Mineralogie*, tom. ii. p. 149. 370.

† *Edinburgh Medical and Surgical Journal*, vol. v.

and filtered; it is also the experiment most easily performed. It is necessary, however, to be known, that by the solution of carbonate of potassa alone, a greenish precipitate is produced, when a certain quantity of it is added. This has not, indeed, the grass-green of the other, but is a bluish-green; in making the experiment, however, with candle-light, the difference is not very conspicuous, especially if we have not the advantage of contrast. The experiment, therefore, ought to be made in day-light, and, at the same time, a solution of carbonate of potassa alone ought to be added to a portion of the solution of sulphate of copper employed, observing the same proportion as in the solution with the arsenic. The difference in the two precipitates will be obvious. The last experiment, Dr Bostock has justly remarked, is the least decisive; the smell is not very evident, unless the arsenic is in considerable quantity, and if it be mixed either with animal or vegetable matter, is nearly disguised.

It is to be added, that these difficulties exist only where a very small quantity of arsenic is operated on. If we have procured a larger quantity, the experiments may be conducted so as to be free from fallacy; the first alone may be rendered decisive, and, where it is practicable, ought always to be performed.

CHAP. XVIII.

BISMUTH.

THIS metal appears to have been imperfectly known to the alchemists. Pott and Geoffroy distinguished it with accuracy; Rouelle and Darcet submitted it to an experimental investigation; and Bergman undertook the examination of its properties and combinations.

It is of a white colour, with a tinge of yellow, with the full metallic lustre, but liable to tarnish from exposure to the air. Its texture is very distinctly foliated, the folia being large. Its hardness is between that of copper and that of lead. It is not ductile, and scarcely malleable; for although flattened a little by the hammer, and rendered denser, it cannot be reduced to thin plates. Its specific gravity is 9.822.

Bismuth occurs native, and likewise mineralized by oxygen and by sulphur. The uses of this metal being very limited, it is scarcely wrought on a large scale. What is used, is generally native bismuth, freed by fusion from the substances with which it is naturally mixed.

Bismuth is one of the most fusible of the metals. Its fusing point, according to Lewis, is 460° ; according to Irvine, 480° . It is easily crystallized, its crystals being rectangular prisms, or octaedrons. By raising the heat considerably above its melting-point, it is volatilized.

If, when in fusion, the air is freely admitted to its sur-

face, it is soon covered with a film which increases, and a greenish-grey powder accumulates, which is an oxide, the metal having increased in weight about one-twelfth. If the metal be exposed to a stronger heat, it burns with a small blue flame, and emits vapours, which condense into a yellow powder, in which the metal is more highly oxidized, as it gains still more weight : each of these oxides is fused by heat into a glass, transparent, and of a green or yellow colour. A white precipitate is obtained from the solution of bismuth in nitric acid, by the affusion of water, which some of the chemists have considered as the metal in a higher degree of oxidizement, but there can be no doubt that it is a sub-salt.

Bismuth is oxidized and dissolved by a number of the acids. The affinities of the acids to the oxide in these combinations appear to be weak, as the greater number of them are decomposed by the affusion of water, the oxide of bismuth, retaining a portion of acid, being precipitated.

Sulphuric acid, when boiled on the metal, is decomposed, the bismuth attracting part of its oxygen, and sulphurous acid, or even sulphur if the heat is high, being evolved. The residual mass is decomposed by water, which divides the salt into two compounds,—a sub-sulphate that remains insoluble, and a super-sulphate that is dissolved, and affords by evaporation acicular crystals. Sulphurous acid combines with oxide of bismuth, and forms an insoluble compound.

Nitric acid acts with great violence on metallic bismuth : very dense red vapours are extricated, and the metal is so highly oxidized, that much of it remains in the form of a white powder uncombined with the acid. When

the action is moderated by the dilution of the acid, the metal is dissolved. The solution is colourless, and, by evaporation, affords rhomboidal crystals, which are permanent in the air, and which detonate slightly when thrown on burning fuel. Either the solution or the salt itself is decomposed by water, a sub-nitrate of bismuth being precipitated, and a super-nitrate remaining in solution. The colour of this precipitate is a pure white, as more or less water has been used to precipitate it. It was formerly named the Magistery of Bismuth, and has generally been said to be the substance used as a paint for the complexion, under the name of Pearl White. It is too acrid, however, for this purpose: the proper pearl white is the tartrate of bismuth, prepared by precipitating nitrate of bismuth by tartrate of potassa.

Muriatic acid scarcely acts upon bismuth in its metallic state, but readily dissolves its oxides. If the solution be evaporated to dryness, and exposed to a moderate heat, it sublimes, and condenses in the state of a thick soft mass, which congeals by cold, and melts in a gentle warmth, and which was formerly named Butter of Bismuth. It is deliquescent, and, like the other salts of bismuth, is decomposed by water. A similar compound is formed by the action of oxymuriatic acid. When this acid is in the state of gas, the particles of bismuth are inflamed when projected into it.

The actions of the other acids on bismuth have been little examined. Phosphoric acid does not act on it, but with the oxide it combines, forming a compound which is insoluble, and which fuses before the blowpipe into a transparent glass. Fluoric acid likewise dissolves the ox-

ide. The taste of the solution is sweetish, and, when it is concentrated by evaporation, it deposits a compound, which is not easily dissolved in water. Boracic acid and carbonic acid may be combined with the oxide by double affinity, and form insoluble compounds.

The salts of bismuth are decomposed by the alkalis; and the precipitates which are thrown down, are dissolved by boiling in a solution of soda or potassa, or by digestion with liquid ammonia.

Bismuth does not unite with hydrogen or carbon. It combines with sulphur by fusion, and forms a compound of a grey colour, having the metallic lustre. When melted, and allowed to cool slowly, it concretes into a crystalline mass, composed of tetraedral prisms crossing each other, shining, and often iridescent. Both the metal and its oxide combine with, or are at least acted on by sulphuretted hydrogen. The metal, exposed to the gas, is tarnished; and any of the solutions of bismuth acquires a dark colour, when placed near to any substance emitting this gas, so as to form a very subtle sympathetic ink. The alkaline sulphurets, or rather sulphuretted hydro-sulphurets, throw down from these solutions very dark-coloured precipitates.

To phosphorus this metal appears to have a very weak affinity, Pelletier being unable, by the various processes he was accustomed to employ, to combine them, in any sensible quantity, or so as to alter the properties of the bismuth.

Bismuth unites with many of the metals, and, in general, communicates brittleness and fusibility; but few of these alloys have been very particularly examined, or ap-

plied to any use. A very small portion, alloyed with gold, destroys completely the ductility of the latter metal : the merely keeping them in fusion in separate vessels near to each other, has this effect ; and the alloy is perfectly brittle when the proportion of bismuth is less than $\frac{1}{1000}$. It also renders the colour of gold very pale. Silver is likewise rendered brittle by an alloy of it, and acquires a yellow colour. The ductility of platina is equally impaired by it : the alloy is fusible, and assumes a purple colour from exposure to the air. With quicksilver bismuth combines very easily ; the amalgam being of different degrees of consistence, according to the proportions. If the proportion of bismuth be not considerable, the fluidity of the quicksilver is even not much diminished : if it be large, as half the weight of the mercury, the amalgam, though at first soft, becomes gradually firm, and is even capable of assuming a crystalline arrangement. Copper and bismuth form an alloy of a reddish-white colour, and foliated texture. Iron unites very imperfectly with it, though the iron, exposed at a high temperature to its action, is rendered brittle. With lead it unites very easily, the lead becoming harder, but at the same time more brittle : the alloy is also more fusible. From the property which bismuth thus has of increasing the fusibility of lead, as well as of other metals, it has been used in the adulteration of quicksilver. If lead alone were added to the quicksilver, the impurity would be discovered by a diminution of its mobility, but the addition of a little bismuth along with it, prevents this, obviously by adding to the fusibility of the compound. This property of bismuth is also well dis-

played in the formation of what has been named the Fusible Metal, which consists of eight parts of bismuth, five of lead, and three of tin. It melts at the temperature of boiling water ; and if one part of quicksilver be added, it melts at a heat considerably lower. A composition of this kind is used for coating the internal surface of glass globes : it is composed of two of bismuth, one of lead, one of tin, and four of quicksilver ; and it fuses with so gentle a heat, that when a little of it is put into the glass-globe quite clean and dry, on putting this in warm water, the alloy is melted, and, by revolving the globe, may be spread over its surface, to which it adheres. An alloy, composed of equal parts of tin, bismuth, and mercury, (the tin and bismuth being first melted, and when becoming solid, the quicksilver being added), forms what has been named Mosaic Silver, from its flaky silvery appearance : it is used to give this appearance to plaster casts, paper, &c. The alloy of equal parts of bismuth and tin alone, is so fusible as to melt at 280° of Fahrenheit : when the proportion of tin is larger, the alloy is less fusible ; it is at the same time harder than tin ; and hence bismuth is sometimes added in the composition of pewter. With zinc bismuth does not combine, which is singular, as their fusibilities are not very different. Nickel appears to be capable of uniting with bismuth, forming an alloy brittle, and in brilliant scales. Its combination with cobalt is doubtful, though they may be united by the aid of nickel or arsenic, and occur in this state in nature. It does not unite with manganese.

Bismuth is applied to few important uses. It is principally in the composition of a few metallic alloys that it is

employed, particularly to give hardness to lead, and fusibility to some others. Its soft alloy, with tin and antimony, has been proposed to be employed to take impressions of medals, as it gradually acquires greater hardness, and can thus preserve the impression it has taken.

CHAP. XIX.

ANTIMONY.

THE name Antimony was given by the alchemists to a mineral of a dark grey colour, metallic lustre, and striated texture ; which was afterwards discovered to be the natural combination of a peculiar metal with sulphur. The name is, therefore, in the modern chemical language, appropriated to this metal, though, by the older writers, and even at present in commerce, it is applied to the native sulphuret. When used in this last sense, the epithet Crude is generally added to it. No metal has been more the subject of chemical investigation, from its preparations having been so long and so extensively employed in the practice of medicine ; and its history, in this point of view, is still of considerable importance.

Antimony, in its pure state, is of a white colour, with a shade of bluish-grey : its lustre is metallic ; and it is not liable to tarnish much from exposure to the air. Its texture is very distinctly foliated : its hardness is moderate, nearly the same as that of tin : it is quite brittle, incapable of extension, and easily reduced to powder by beating. Its specific gravity is 6.702.

Antimony is found native, and mineralized by oxygen, by sulphur, and perhaps by muriatic acid. It is from the native sulphuret that it is always extracted. The ore is first freed from the earthy matter naturally mixed with it, by fusing it in a large earthen pot or crucible covered at the top, and perforated in the bottom, another pot being placed beneath to receive the melted metallic sulphuret, or by melting the ore covered with charcoal powder in the bed of a reverberatory furnace. This forms what is named Crude Antimony. From this the antimony is usually procured, by fusing it with iron-filings. On 32 parts of these heated to redness, 100 parts of the sulphuret are projected, and when the whole is in fusion, 20 parts of nitre are added: the sulphur of the sulphuret is combined partly with the iron, partly with the alkali of the nitre, and the metallic antimony remaining in fusion is poured into conical iron moulds. Or it may be procured probably in a purer state, by exposing the sulphuret for some time to a moderate heat, by which the sulphur is dissipated, and the metal very imperfectly oxidized. It is then fused with an equal part of black flux, or of crude tartar: the metal is reduced, and, being very easily melted, is run out.

Antimony melts a little above a red heat, or about 810 of Fahrenheit. When cooled slowly and partially, so that the internal liquid portion can be withdrawn from the external solid crust, the inner surface of the latter is covered with crystals, in the form of single and double tetraedral pyramids. Even when an entire mass of it is congealed, there frequently appear on the surface stellated spots, from crystallization, and its entire structure is

crystalline, being composed of rhomboidal plates, intersecting each other, and divisible in certain directions. When the temperature is raised to a full white heat, the antimony sublimes in close vessels, and condenses, forming a brilliant metallic crust.

When the metal is exposed to heat in contact with the air, it is converted into a grey powder, which is an imperfect oxide. This is even more volatile than the metal. If it be exposed to heat, it sublimes; receiving at the same time a larger portion of oxygen, and condensing in acicular crystals. The same oxide is at once obtained by exposing the antimony to such a degree of heat, with the admission of air, as is sufficient to volatilize it. It then burns with a feeble flame. It is also obtained perhaps still more highly oxidized, by deflagrating antimony in filings with twice its weight of nitre in a crucible heated to ignition. Prepared in this mode, however, it retains a portion of the alkali of the nitre combined with it, which is not easily abstracted by washing, and which renders it capable of vitrifying when exposed to a high heat.

A more full investigation of the degrees of oxidization of which antimony is susceptible, was undertaken by Thenard. According to this chemist, there are not less than six oxides of antimony capable of being distinguished from each other, and of having their degrees of oxidization determined. The first is of a black colour: it is obtained by precipitating antimony from its solutions by iron or zinc: it contains only 0.02 parts of oxygen. The second is of a chesnut-brown colour: it is obtained by exposing to heat in close vessels, either of the two oxides, which are at the highest degrees of oxi-

dizement, and which thus lose a portion of their oxygen. This oxide contains 0.16 of oxygen, and is the base of the vitrified oxide, or glass of antimony as it has been named. The third is orange-coloured : it contains 0.18 of oxygen, and is obtained by the same process as the preceding one, stopping the operation when the orange colour is attained. The fourth is yellow, and contains about 0.19 of oxygen : this also is obtained by the same process, being the first result of the partial de-oxidizement. The fifth, containing 0.20 of oxygen, is white ; it is prepared by exposing antimony to such a heat as volatilizes it, the air being admitted ; and it exists in several of the saline combinations of the metal, as the tartrate and muriate. The sixth is also of a white colour, and contains 0.32 of oxygen : it is prepared by oxidizing antimony by deflagration with nitre : the oxide that is formed remains in combination with the alkali of the nitre, and the compound is partially soluble in water : On adding an acid to this solution, the oxide is precipitated : it is scarcely soluble by itself in water, and combines with difficulty with the acids. By exposing it to heat with various proportions of metallic antimony, it forms the other oxides *.

Proust has sought to simplify this subject, and, in conformity to his views of metallic oxidation, has endeavoured to establish that antimony is susceptible of only two degrees of oxidizement ; the one at the *minimum*, containing 18.5 of oxygen in 100 parts, the other at the *maximum*, containing 23. The first is the base of the greater number of saline combinations of antimony, and is ob-

* Annales de Chimie, tom. xxxii. p. 259.

tained by decomposing the muriate of antimony by water, and boiling the precipitate which that decomposition affords, with a solution of carbonate of potassa to abstract the whole of the acid from the oxide. It is of a yellowish-white colour, and is fusible by heat, forming an opaque and crystalline mass : it is also volatile, and forms crystals by sublimation. The second is procured by distilling nitric acid from antimony. It is not melted at a red heat, but is volatilized, and condenses in acicular crystals : it is not soluble in water, and is not easily dissolved by acids : it is nearly the same with the oxide obtained by raising antimony to a high temperature in atmospheric air, or deflagrating it with nitre *.

Little is advanced by Proust in support of his assertions, and in opposition to the results of Thenard's investigations. They rest entirely on the vague assumption of what he calls a law of nature, that metals are susceptible only of two degrees of oxidizement. Thenard's conclusions, independent of resting on experiment, are more conformable to the just view of metallic oxidation, which, where not limited by peculiar circumstances, may undoubtedly take place in numerous, and perhaps indefinite proportions. And although it is perhaps true, that the composition of the oxides which Thenard has enumerated, cannot be ascertained with precision to a hundredth part, yet it is probable that they exist ; or that there is a series between the minimum and maximum different in the degrees of oxidizement, and distinguished, it may be, by the properties he has assigned.

* Journal de Physique, tom. lv. p. 325.

All the oxides of antimony are easily reduced by exposure to heat with carbonaceous matter.

Antimony suffers little change from water at a low temperature, but it decomposes it at that of ignition. It is acted on by a number of the acids.

Sulphuric acid boiled on antimony oxidizes it, sulphurous acid being disengaged, and a portion of the sulphuric acid being combined with the oxide, and forming a humid white mass. This is decomposed on the affusion of water, a sub-sulphate of antimony remaining undissolved, and a super-sulphate being dissolved; the solution becomes turbid without crystallizing when evaporated. Sulphurous acid, with the assistance of heat, oxidizes the metal, and a compound is formed, which, according to Vauquelin, is a sulphuretted sulphite of antimony. The sulphurous acid may be combined with the oxide of antimony, by adding it to the antimonial salts: it forms a white precipitate, sparingly soluble, and of an acrid taste, which is first fused, and afterwards volatilized and decomposed by heat.

Nitric acid oxidizes antimony, the degree of oxidizement being so high when the acid is concentrated, that the oxide does not combine with so much of the acid as to form a proper solution.

Muriatic acid acts very slowly on antimony, the disposing affinity it exerts not being sufficiently powerful to attract the oxygen of the water rapidly. A solution, however, is at length effected. The oxides of antimony are readily dissolved in it; and there are some indirect processes which the chemists were accustomed to employ to obtain muriate of antimony. Antimony, either pure,

or in the state of the native sulphuret, was mixed with corrosive muriate of mercury, and exposed to heat in a retort: the oxygen and muriatic acid passed from the mercury to the antimony, and the muriate of antimony being volatile, was sublimed. Or, according to the process in the modern pharmacopœias, the brown oxide of antimony in powder is mixed with muriate of soda and sulphuric acid, and heat applied to the mixture in a retort: the muriatic acid, disengaged from the muriate of soda by the sulphuric acid, combines with a portion of the oxide of antimony, and the muriate thus formed is obtained by sublimation. Obtained by either of these processes, it is condensed, partly in a liquid state, partly in the state of a soft mass, which, from its consistence, was named by the older chemists Butter of Antimony. When this is exposed to the air, it also becomes liquid by attracting water; but if water be directly added, either to it or to the liquid solution, it immediately decomposes it: a very copious white precipitate is thrown down, formerly known by the name of Powder of Algaroth, and supposed to be an oxide of antimony, but now proved to be a sub-muriate. The water above holds dissolved a super-muriate, having a great excess of muriatic acid. The muriate of antimony is highly caustic: it is very fusible, and, as its preparation shews, is also volatile.

A similar compound is formed by the action of oxymuriatic or nitro-muriatic acid on antimony. Filings of antimony, projected into oxymuriatic acid gas, exhibit a very vivid combustion, and muriate of antimony condenses on the sides and bottom of the vessel. Oxymuriatic acid gas transmitted through water over sulphu-

ret of antimony, likewise oxidizes and dissolves the metal. Nitro-muriatic acid is the proper solvent of antimony, or that by which a concentrated and permanent solution is most easily obtained. It is equally decomposed, however, by water, and is indeed merely muriate of antimony in a concentrated state. The nitro-muriatic acid likewise dissolves the antimony in the native sulphuret, the sulphur being left undissolved.

The greater number of the other acids, though unable to oxidize and dissolve antimony, are capable of combining with its oxides, either directly by adding the oxide to the acid, or by a complex affinity, resulting from mixing, with a solution of an antimonial salt, the solution of a salt containing the acid with which the oxide is designed to be combined. Phosphate of antimony, obtained by such processes, has been described as being in the state of a soft mass, which is not crystallizable, and is changed by fusion into a transparent glass. Mr Chenevix, in his researches on James's powder, found, however, that phosphoric acid could not by any process of single or double affinity be combined with oxide of antimony. The fluuate, borate, and carbonate, are unknown.

Mutual actions are exerted between antimony or its oxides, and several of the salts; and some of these are of importance, from their use in the practice of medicine.

When antimony, or its native sulphuret, or its brown oxide, is exposed to heat with a large quantity of nitre, it is completely oxidized, as has been already remarked, and this oxide remains in combination with the potassa of the nitre. By washing with water, it is resolved into two compounds, one with an excess of alkali, which is dissol-

ved; the other, which remains undissolved, and which consists of the oxide, with a smaller quantity of alkali so strongly combined with it, that it cannot be entirely removed by washing with water. This is what was formerly named Calcined or Diaphoretic Antimony. It was regarded as a pure oxide. Berthollet shewed that a part of the alkali of the nitre was contained in it. This, according to Thenard, amounts to about one-fifth.

The most important preparation obtained by the action of any of the compound salts on antimony, is that from the action of the super-tartrate of potash on oxide of antimony. It is the tartrate of potassa and antimony, long known by the name of Emetic Tartar, and superior to all the antimonials in the certainty of its operation. Various processes have been followed to prepare it, differing principally in the oxide that is employed. The brown oxide of antimony, prepared by deflagrating sulphuret of antimony with an equal weight of nitre, is now ordered in the pharmacopœias; or, what is perhaps preferable, the vitrified brown oxide may be employed. Three parts of either of these in fine powder, are boiled with four parts of super-tartrate of potassa, and 32 parts of water, in a glass vessel. The liquor, after half an hour's ebullition, is strained through paper, and set aside to crystallize. These crystals are the tartrate of antimony and potassa; the excess of tartaric acid in the super-tartrate dissolving a portion of the antimonial oxide, and this triple salt crystallizing. According to the analysis of it by Thenard, it consists of 38 of oxide of antimony, 16 of potassa, 34 of tartaric acid, and 8 of water of crystallization*.

* Nicholson's Journal, 4to, vol. v. p. 271.

Its crystals are triedral pyramids, which effloresce slightly on exposure to the air. It is soluble in about 15 parts of cold water, and in much less boiling water. In a state of solution it is slowly decomposed from the decomposition of its acid: it is also decomposed by heat. Its value as an antimonial medicine is derived from the uniformity and comparative mildness of its operation.

Another important preparation, belonging perhaps to the same class, is that which has been named Phosphate of Antimony and Lime. An empirical remedy, known by the name of James's Powder, had been celebrated for its efficacy in the treatment of fever. Its composition was unknown, farther than that it was an antimonial preparation, until its analysis was undertaken by Dr Pearson *. He discovered that it consists of 43 parts of phosphate of lime, and 57 of oxide of antimony, part of this oxide (about 28 in 100 parts of the powder) being in a vitrified state, and insoluble in any acid. And he found, that by calcining equal parts of sulphuret of antimony and bone-shavings in an open fire, and afterwards exposing the powder in a covered crucible to a white heat for two hours, a preparation similar in chemical composition and medicinal operation is obtained. The theory of its formation is obvious: the animal matter of the bones is decomposed by the heat, and dissipated, leaving the phosphate of lime, which is their basis: the sulphur of the sulphuret is also expelled, and the antimony is oxidized and partially vitrified. It is uncertain, whether in

* Philosophical Transactions, 1791, p. 317.

either preparation the phosphoric acid remains exclusively united with the lime, and this phosphate of lime is merely mechanically mixed with the oxide of antimony; or whether it is in combination both with the lime and the oxide, forming a ternary compound. Mr Chenevix, supposing that a degree of uncertainty must always attend the preparation, from the volatility of the antimonial oxide, and its variable state with regard to vitrification, proposed a method of forming it in the humid way, by dissolving equal weights of sub-muriate of antimony and pure phosphate of lime in muriatic acid, and pouring this into liquid ammonia, diluted with water, when a precipitate is thrown down *. It is certain, however, that this cannot be the same preparation: it must contain muriatic acid; and none of the oxide is vitrified, which must give rise to a difference in its power.

The alkalis appear to be capable of acting on antimony and its oxides. In boiling a solution of soda or potassa on sulphuret of antimony, the action of the alkali, or perhaps rather of the alkaline sulphuret, appears to promote the oxidizement of the metal. And in the action of nitre on antimony or its sulphuret, already described, it has been seen that the alkali of the nitre enters into very intimate combination with the perfect oxide, forming a compound, to a certain extent soluble in water, and capable of crystallizing.

Antimony combines very readily with sulphur by fusion, and forms a compound very similar to the native sulphuret. In this combination, according to Proust, 100

* Philosophical Transactions, 1801, p. 395.

parts of antimony combine with 35 parts of sulphur by weight *. Its oxides appear also to combine with sulphur. According to Proust, indeed, these latter combinations do not take place : when sulphur is mixed with oxide of antimony, either at the minimum or maximum of oxidizement, and exposed to heat, the oxide, he affirms, is always decomposed, sulphurous acid disengaged, and a metallic sulphuret formed ; and if oxide of antimony appear in certain preparations to be combined with sulphur, it is only, he supposes, by the medium of metallic antimony †. This last, however, is only an hypothesis, and is not very probable, though asserted with that decision and dogmatism often conspicuous in the writings of Proust. It may happen, as he affirms, that when sulphur and the oxides of antimony are heated, sulphurous acid is always disengaged : but this only proves that a partial, not that a complete de-oxidizement takes place ; and there are facts to be immediately stated, which appear to prove, that sulphur and the oxides of antimony combine.

From the sulphuret of antimony being procured native, and from the metal having been even for a long time scarcely known, it has happened that many preparations have been formed from the sulphuret, instead of from the pure metal, and have derived from this some peculiarities of composition. Of some of these, which are still frequently objects of attention to the chemist, as well as to the physician, it is necessary to take notice.

* *Journal de Physique*, tom. lv. p. 332.

† *Ibid.* p. 325.

If the sulphuret be exposed in a shallow earthen vessel to a heat not sufficient to fuse it, sulphureous fumes arise, and if the fire be gradually raised, it is converted into a grey powder, which is an imperfect oxide, retaining a portion of sulphur. If this be exposed in a crucible to a very strong heat, it melts, and forms a transparent glass of a reddish-brown colour. This is what was formerly known by the name of *Glass of Antimony*: it may be named the Vitrified Sulphuretted Brown Oxide. It generally contains, as Vauquelin discovered, a portion of silex, amounting to 9 or 10 parts in 100, derived from its action on the crucible in which it is prepared *.

Proust has considered this substance as a compound of oxide of antimony and sulphuret of antimony, in the proportion of about eight parts of oxide of antimony, and one of sulphuret of antimony, and has shewn that it is formed by melting oxide of antimony and sulphuret of antimony in these proportions. But it is much more probable, that, in such an experiment, the metal of the sulphuret shares the oxygen of the oxide, and that the compound is merely a sulphuretted oxide. According to Thenard, it is the brown oxide, or that containing 0.16 of oxygen, that is the basis of this preparation.

The metal, existing in the native sulphuret, is likewise oxidized, and this oxide combined with a proportion of sulphur, by deflagrating it with nitre. If equal parts of them in powder are projected into an ignited crucible, a vivid deflagration takes place: the greater part of the sulphur is converted into sulphurous acid, and dissipa-

* *Annales de Chimie*, tom. xxxiv. p. 138.

ted ; and the antimony is oxidated, though not to a high degree, this oxide retaining a portion of sulphur combined with it. It has been known by the name of *Saffron of Antimony*. The principal difference between it and the preceding preparation is, that the proportion of sulphur is larger, and perhaps the metal less perfectly oxidized. Proust, however, considers it as oxide of antimony and sulphuret of antimony, in the proportions of eight of the former and two of the latter ; and it is perhaps not impossible, but that, from the rapidity of the deflagration, a portion of the metal may escape oxidizement.

When sulphuret of antimony is fused with an alkali, potassa for example, and thrown into water, or when an alkaline solution is boiled upon it, (six parts of sub-carbonate of potassa, one-twentieth of the weight of this of sulphuret of antimony, and twenty parts of water being boiled together), the antimony is oxidized, and combined with the sulphur and sulphuretted hydrogen existing in the solution, so as to be soluble in water. If the liquor is strained while hot, it is transparent and nearly colourless ; but as it cools, it deposits a powder of a lively brick-red colour, known to the chemists by the name of *Kermes Mineral*, and much used on the Continent as an antimonial medicine. If, instead of allowing the liquor to cool, diluted sulphuric acid is added to it while hot, a little sulphuretted hydrogen is disengaged, and a copious orange-coloured precipitate is thrown down, which has been known by the name of *Golden Sulphur of Antimony*, and which has been more used in this country than the kermes, though it is now little employed. It has been an object of much investigation to chemists to determine

the nature of these preparations, and the chemical distinctions between them. Bergman discovered the existence of sulphuretted hydrogen in them, and Thenard lately analysed them minutely. He found, that the kermes mineral consists of 72.760 of the brown oxide of antimony, 20.298 of sulphuretted hydrogen, and 4.156 of sulphur; while the other, the golden sulphur as it is named, is composed of 68.3 of the orange oxide of antimony, with 17.877 of sulphuretted hydrogen, and 11 or 12 of sulphur, intermixed with it from the mode of its preparation *. According to this view, the principal difference between these preparations is the degree of oxidizement of the base, which in the golden sulphur is rather higher than in the other. But as the two preparations may be obtained from the same solution, there appears to be no cause by which a difference in the degree of oxidizement can be produced: the base must be the same; and the opinion of Trommsdorff † is more probable, that the essential difference between them is in the golden sulphur containing a larger proportion of sulphur. This appears to follow from their mode of preparation. The kermes is merely deposited from the solution, and the portion of sulphur and sulphuretted hydrogen combined with the oxide, must be only the portions which that oxide can attract, while quantities of each of them must still be retained by the alkali. The golden sulphur is, on the other hand, precipitated by the addition of an acid, which must saturate the alkali: the sulphuretted

* *Annales de Chimie*, tom. xxxii. p. 268.

† *Ibid.* tom. xxxiv. p. 132.

hydrogen combined with that alkali appears to be disengaged, while the sulphur combined with it must be precipitated; and hence more sulphur must enter into the composition of the precipitate thus obtained, (which is the golden sulphur), than into the composition of the other, which is deposited without this saturation of the alkali by an acid. And the proportion of sulphur in the former will even be different, if the acid is gradually added, in the quantity that first falls down, from what it is in the quantity last precipitated.

Sulphuretted hydrogen added to antimonial salts gives an orange-coloured precipitate from combining with its oxide; and a similar precipitate is formed by the hydro-sulphurets and sulphuretted hydro-sulphurets.

Antimony combines with phosphorus, by either of the usual methods of forming the metallic phosphurets. The phosphuret of antimony presents brilliant facets, is of a white colour, brittle, and fusible.

Antimony combines with the greater number of the metals: in general, its alloys are brittle, and of a foliated texture. Few of them have been applied to any use. It very much impairs the ductility of gold, even when in a quantity less than $\frac{1}{1000}$ of the mass. The largest quantity of antimony which gold can fix, appears to be about 1 part to 15. The alloy is of a dull grey colour, brittle, and of a fine grain. Silver is also rendered brittle by it, as is platina; nor is the antimony easily expelled entirely from either metal by heat. It does not easily amalgamate with quicksilver, and the amalgam obtained by heat is very imperfect. Copper forms with antimony a pale and brittle alloy: when the proportions are equal parts of the

two metals, it is of a violet colour, and has a striated texture. Iron and antimony easily unite by fusion : the alloy, when of equal parts, is hard, brittle, and, in its fracture, presents small facets : the magnetic quality of the iron is entirely destroyed. The alloy of antimony with lead, is almost the only one of its alloys applied to any use : it forms the metal of which printing-types are cast. The proportions are various, but, in general, it consists of 80 parts of lead, with from 15 to 25 of antimony, the proportion of antimony being larger as the type is to be small. It is tolerably hard ; has considerable tenacity ; and there is some reason to believe, that it derives from antimony the property of expanding in becoming solid, whence it takes a fine impression from a mould, and is therefore well adapted to the purpose to which it is applied. Antimony, combined with tin, adds to its hardness, but renders it at the same time more brittle. According to a late examination of this alloy, however, by Thenard, this is owing to the presence of lead. Four parts of tin, and one of antimony, form an alloy which is very ductile ; and even when composed of equal parts, considerable ductility remains. A singular fact was observed by Thenard, in this investigation, that the two metals exert such an action on each other, that the usual effects from re-agents on them are not obtained *. Zinc forms with antimony a hard and brittle alloy. Its alloys with nickel, cobalt, and manganese, have scarcely been examined. It forms with arsenic a hard and brittle alloy, which is easily melted : its alloy with bismuth is also brittle.

* Philosophical Magazine, vol. xxiv. p. 236.

Oxide of antimony appears to combine with some other metallic oxides. A combination of it with oxide of lead, forms the paint known by the name of Naples Yellow. Different recipes, varying much in the proportions of the ingredients, have been given by Beckman, in his memoir on this pigment*.

Oxide of antimony combines with, and promotes the vitrification of some of the earths, giving to their glass a hyacinthine colour.

Antimony is principally used in the formation of certain alloys, especially that for forming printing-types : its oxides are used in the composition of pastes and enamels ; and it is extensively employed in various combinations in the practice of medicine.

CHAP. XX.

TELLURIUM.

THE existence of this metal was suspected by Muller in an ore found in some of the mines in Transylvania, and which afforded a small quantity of gold. He even made experiments on the metal which is combined with the gold in this ore, and Kirwan gave it a place in his mineralogy, under the name of Sylvanite, on the authority of Muller's experiments†. The discovery was

* Philosophical Magazine, vol. iii. p. 278.

† System of Mineralogy, vol. ii. p. 324.

afterwards confirmed by Klaproth, who denominated this metal Tellurium, and to him we are principally indebted for the knowledge of its properties. In several of its qualities, it has a close resemblance to antimony, but in others it differs entirely from that metal. It occurs in nature, alloyed with a small portion of iron and gold; likewise with a considerable proportion of gold and silver: in a third species, farther combined with lead, and a trace of sulphur; and lastly, not only combined with these metals, but also with a little copper and more sulphur.

Pure tellurium, obtained from any of its native combinations, is of a tin-white colour, verging into lead-grey, with a high metallic lustre: its fracture is foliated: it is very brittle, so as to be easily reduced to powder. It is one of the lightest of the metals; its specific gravity being 6.115.

Tellurium is easily fused: it melts before ignition, at a heat somewhat higher than that which melts lead, but below that necessary to melt antimony. It is also capable of being volatilized, and, according to Gmelin, is as volatile as arsenic. When cooled without agitation, its surface presents a crystallized appearance.

When heated before the blowpipe on charcoal, it inflames, giving a vivid light, blue, and greenish on the edges: it is dissipated in greyish-white vapours, having a pungent odour, which, condensed, form a white oxide. If this oxide is heated on charcoal, it is reduced with a kind of explosion, but is again speedily converted into vapour, and oxidized by continuing the heat. If heated in a glass-retort it fuses: and, when solid, has a straw-yellow colour and striated texture. The oxide, precipi-

tated from some of its metallic combinations, appears to contain about 20 parts of oxygen combined with 100 of the metal. It is reduced by being exposed to heat with oil, or any carbonaceous matter.

Tellurium is oxidized and dissolved by the acids.

Sulphuric acid poured on a small quantity of it, gradually acquires, even in the cold, a deep purple colour: On adding water, this colour disappears, and the small quantity of metal dissolved separates in black flocculi. Heat likewise destroys the colour, and a white precipitate is thrown down.

With nitric acid, tellurium yields a limpid colourless solution, which is not rendered turbid by water. The concentrated solution gives, after some time, slender needle-shaped crystals, aggregated so as to form a dendritic appearance.

Muriatic acid, to which a little nitric acid has been added, affords a similar transparent solution: this solution is decomposed by water, and a white precipitate is thrown down, which, Klaproth remarks, is not to be regarded as a pure oxide, but as a sub-muriate: by repeated affusions of water, it is almost entirely dissolved. It is also thrown down by alcohol. Sulphuric acid, diluted with two or three parts of water, to which a little nitric acid has been added, dissolves also a large portion of the metal, and the solution is not decomposed by water.

The alkalis throw down from the saline solutions of tellurium, precipitates of a white colour, which are again soluble in all acids. If an excess of alkali be added, the precipitate is entirely re-dissolved, as it is also by the alkaline carbonates.

The solutions of tellurium are not precipitated, nor rendered turbid by prussiate of potassa,—a property which it has in common with gold, platina, and antimony. Tincture of galls produces a flocculent yellow precipitate.

They are decomposed by several of the metals, which attract the oxygen combined with the tellurium, and precipitate it in its metallic state. This is done by zinc, iron, tin, and antimony. Phosphorus put into the muriatic solution of tellurium is gradually coated with metallic laminæ.

When fused in a gentle heat, with an equal quantity of sulphur, tellurium forms a lead-coloured striated substance. If this be heated to ignition in a retort, part of the sulphur is sublimed, elevating a little tellurium with it. The alkaline sulphurets precipitate it from its solutions, the precipitate being of a brown or black hue. It consists either of the metal or its oxide in combination with sulphur. When placed on burning charcoal, it burns with a pale blue flame, and a white smoke, as the compound of the metal and sulphur formed by their direct union does.

The alloys tellurium forms with the metals have scarcely been examined. It does not easily amalgamate with quicksilver, even when their action is aided by heat *.

The other chemical relations of this metal have not been discovered, nor, from the small quantity of it which can be obtained, has it been applied to any use.

* Klaproth's Analytical Essays, vol. ii. p. 1. &c.

CHAP. XXI.

CHROME.

THIS metal was discovered by Vauquelin. It exists in the state of an acid, combined with oxide of lead, in a beautiful mineral, named Red Lead, found in Siberia, and with regard to which, very discordant analyses had been given by chemists. Vauquelin reduced the metallic acid which he discovered in it to the metallic state, and his researches have been confirmed by those of Klaproth and Gmelin. It derives its name from the splendid and numerous colours which it presents in its saline combinations. It has since been discovered in various minerals, and particularly combined in iron, and in some of the gems, as the emerald and ruby, of which it is probably the colouring matter.

Vauquelin extracted the metal from the red lead ore, by adding to it muriatic acid, which combines with the oxide of lead, and forms a compound that is precipitated, the chromic acid remaining in solution. To abstract a little muriatic acid combined with it, oxide of silver is cautiously added, and the pure chromic acid being decanted from the precipitate of muriate of silver, and evaporated, is exposed to a very strong heat excited by a forge, in a crucible of charcoal, placed within another of porcelain. It is thus reduced to the metallic state. It is

to this chemist that we are indebted principally for a knowledge of its properties*.

Chrome is of a white colour, inclining to grey : it is very brittle : its fracture presents a radiated appearance, needles crossing in different directions with interstices between them. Its other physical qualities have not been determined.

This metal is difficult of fusion. Exposed to the heat of the blowpipe, it does not melt. When fused by having been exposed to the intense heat necessary to its reduction, it presents crystalline filaments, which rise above the metallic mass.

It is oxidized by the action of atmospheric air at a high temperature. When heated by the blowpipe, its surface tarnishes, and is at length covered with a light-green crust, which is an oxide. By a farther oxygenizement, effected by treating it repeatedly with nitric acid, it is brought to the state of an acid, the colour of which is an orange-red. This acid contains, according to Vauquelin's estimate, about 0.40 of its weight of oxygen.

Chrome is not easily acted on by the acids. Even when reduced to a fine powder, and treated with concentrated boiling nitric acid, it is oxidized with much difficulty, and communicates to the acid only a green tinge. Nor is any sensible quantity of it dissolved, until it has been treated repeatedly with considerable quantities of the acid. The neutral combination can scarcely be obtained; and hence the salts of chrome are very little known. Even oxide of

* Memoir translated in Nicholson's Journal, 4to, vol. ii. p. 387.

chrome, according to the observation of Godon, is very sparingly acted on by the acids.

Chrome, in the state of acid, appears to be more susceptible of combination; and this acid being obtained without difficulty from its native combinations, its chemical relations have been more examined.

Chromic acid is very soluble in water: the taste of the solution is sharp and metallic: it is of an orange-red colour: by evaporation, either spontaneous or with a gentle heat, it affords crystals, in long slender prisms, of a ruby-red colour.

This acid is easily partially de-oxidized, or reduced to the state of the green oxide. Heated by the blowpipe on charcoal, it boils, and leaves a green infusible matter. Melted with borax, or phosphoric acid, it gives to the globule an emerald green colour. Paper wetted with it, and exposed to the solar light for a few days, assumes a green colour; and the same colour, which is the indication of its partial de-oxidizement, is produced by immersing iron, tin, or most of the other metals, in its solution; or by boiling the solution for a few minutes with ether or alcohol. Muriatic acid heated with it, produces oxymuriatic acid gas, and the fluid assumes a beautiful deep-green colour. The solution of the chromic acid gives a greenish-brown flocculent precipitate with hydro-sulphuret of potassa, and one of a yellowish-brown colour with tannin.

This acid combines with the alkalis, earths, and metallic oxides, forming neutral salts which are named Chromates.

In combining with the alkalis, it produces salts which

are soluble and crystallizable, but the minute properties of which have not been examined. The colour of their solutions is an orange-yellow, and, by evaporation, they afford crystals of the same colour: they afford oxygen gas by heat, and the residuum of this operation has a green colour. They are decomposed by the mineral acids, and several of the earths, and likewise by double affinity, by the greater number of earthy and metallic salts. The chromate of potassa crystallizes in rhomboidal prisms; that of ammonia, in plates of great brilliancy on the surface. It appears from the observations of Godon *, that the alkalis, in consequence of their affinity to this acid, enable the oxide to attract oxygen from the air, and be acidified, when they are exposed with the oxide to a high temperature.

Chromic acid combines with the earths, and forms compounds resembling the alkaline chromates in their general properties, but, in general, sparingly soluble; at least this is the case, according to Vauquelin, with its combinations with barytes and lime: the former is of a light yellow colour, the latter of an orange-yellow. According to Godon, however, the chromate of lime is soluble and crystallizable. The acid unites, according to the same chemist, with silex, when this earth is in a state of extreme division, and forms a matter of a rose colour, insoluble in water, which is not changed by heat.

The combinations of this acid with metallic oxides are in general possessed of very beautiful colours, and are well adapted to form the finest paints. That with oxide

* *Annales de Chimie*, tom. liii. p. 224.

of lead has an orange yellow, of various shades; that with mercury, a vermilion red; with silver, a carmine red; with zinc and bismuth, the colours are yellow; with copper, cobalt, and antimony, they are dull.

The combinations of this metal with the simple inflammables, or with the other metals, have not been examined.

Were it discovered in any considerable quantity in nature, it would furnish in its combinations the most beautiful and durable paints,—a purpose, indeed, to which it has already been applied in miniature-painting; and it is probable that it would also communicate colours equally rich to porcelain and glass.

CHAP. XXII.

MOLYBDENA.

THE name Molybdena was given to a mineral so similar in its appearance, and in several of its qualities, to plumbago, that they were confounded as varieties of one substance. Scheele discovered that it possessed chemical properties different from those of plumbago; and he farther discovered, that it contained sulphur, and that a peculiar metallic acid might be extracted from it. This has been reduced to the state of a metal, to which the name of Molybdena is now appropriated. It bears some resemblance to chrome in the various colours which its compounds assume, but it differs very widely from it in

other properties. It has been examined by Pelletier, Hielm, Klaproth, Hatchet, and other chemists; and, more lately, minutely by Bucholz*.

There is only one ore of this metal, that in which it is mineralized by sulphur. It exists also in the state of an acid in an ore of lead. Different processes have been followed to extract it from the sulphuret. The most simple, and, at the same time, that which affords it most pure, is to treat it with nitric acid. On one part of it reduced to powder, five parts of diluted nitric acid are poured, and distilled from it to dryness; the distillation being repeated with new portions of the acid three or four times. The sulphur is thus converted into sulphuric acid, the molybdena into molybdic acid or oxide; the former is removed by washing with warm water; the latter, being sparingly soluble, remains in the form of a powder. Another process, employed as well as the preceding one by Scheele, is to deflagrate the native sulphuret of molybdena with four times its weight of nitre. Sulphate and molybdate of potassa are formed. These, with a portion of undecomposed nitre, are dissolved by warm water; the oxide of iron, often contained in the native sulphuret, being left undissolved: by evaporation, the sulphate of potassa and the nitre crystallize: the compound of molybdic acid and potassa remains uncrystallizable: it is diluted with water, and by adding to it sulphuric acid, the molybdic acid is separated and precipitated, care being taken not to add an excess of acid, by which it might be re-dissolved. The acid, however, separated in this way,

* Nicholson's Journal, vol. xx. p. 125.

still retains a small quantity of the alkali combined with it, which, according to Scheele, may be separated by dissolving the precipitate in as small a quantity of water as possible, and boiling it for a few minutes with nitric acid *, —a method, however, which Bucholz found to succeed very imperfectly. In his investigation of the subject, he found, that by mere calcination in the open fire, the sulphur of the native sulphuret is dissipated, and the molybdena brought to the state of an acid. On this he founded a process, which had indeed been given before by Hielm †, more economical than either of Scheele's, and affording the molybdena more pure. The native sulphuret in powder, is calcined in an open crucible with a strong fire, stirring it constantly, and diminishing the heat towards the end of the process, to prevent the fusion of the molybdic acid, and its combination with a little argil and oxide of iron which the sulphuret contains. The residuum, reduced to powder, is digested repeatedly with liquid ammonia, with which the molybdic acid combines, leaving the other substances present undissolved. The different solutions are mixed together, and evaporated to dryness: the heat is raised to incandescence, by which the ammonia is expelled, and the molybdic acid remains, more or less completely reduced by the action of the ammonia favoured by heat ‡.

The reduction of molybdic acid to the metallic state, or rather the fusion of the metal into a globule or mass,

* Scheele's Chemical Essays, p. 227.

† Crell's Chemical Journal, vol. iii. p. 317.

‡ Philosophical Magazine, vol. xvi. p. 202.

is extremely difficult. Scheele when he attempted it did not succeed; and Pelletier was equally unsuccessful; for although he reduced the molybdena by exposing its acid with charcoal and a little oil to the metallic state, it was so slightly agglutinated as to break under the fingers *. Hielm made an extensive series of experiments with this view, and although many of them failed, in some others he succeeded, when a very intense heat was excited in the furnace by a powerful blast. The molybdic acid was reduced to a kind of slag, losing in this reduction about 25 *per cent.* of weight; and in some of the experiments metallic globules were obtained †. Bucholz appears to have succeeded still more completely, by urging molybdate of ammonia, or molybdic acid, surrounded with charcoal powder, with the most intense heat that could be raised by a forge-fire. After repeated experiments, a mass, composed of scales agglutinated, and some small globules, both having metallic lustre, were obtained. And in repeating the experiment he procured pieces of one or two drachms, almost entirely fused, having a spherical surface, and metallic lustre ‡.

Molybdena in its metallic state, appears, from the experiments of Hielm, to be of a yellowish-grey colour, with metallic lustre: according to Bucholz, it is of a silvery white: it presents a granular fracture; is hard so as not to be easily broken by the hammer; but does not appear to have any ductility or malleability. Its specific

* Mémoires de Chemie, tom. i. p. 213.

† Cell's Chemical Journal, vol. iii. p. 174. 180. 185. 339. 357.

‡ Nicholson's Journal, vol. xx. p. 132.

gravity Hielm found to be 7000, and when its interstices were diminished, probably by more perfect fusion or compression, 7.400. Bucholz found it to be 8.611.

It is evidently one of the most infusible of the metals. It is however easily oxidized. It is scorified on its surface by the external flame of the blowpipe. Bucholz, in exposing it to heat in a crucible, observed, that at a red heat it became of a brownish-yellow colour, which soon changed to violet, inclining to indigo. Pelletier remarks, that by calcination it is changed into a white oxide, and that it suffers a similar change by deflagration with nitre, the oxide remaining in combination with the alkali of the nitre. When fully oxygenized, it becomes soluble in water, and acquires the properties of an acid.

Mr Hatchet, in his experiments on the native molybdate of lead *, concluded, that this metal is susceptible of four marked degrees of oxidizement; in the lowest degree it forms a black oxide; in the second, one of a blue colour; in a third, a green; and when saturated with oxygen, it forms the molybdic acid. These are best shewn in the de-oxidizement of the acid. When subjected to the action of substances which partially abstract its oxygen, as, for example, by immersing in its solution any of the metals, except gold and platina, by transmitting through it a stream of hydrogen gas, or even by the action of light, it becomes blue. The green oxide appears to exist in some of the saline combinations of the metal, and is produced particularly in the action of nitric acid on some of the solutions of molybdena, which

* Philosophical Transactions, 1796, p. 336.

it changes, first to a blue colour, then to a green, and at last to a yellow, of which last colour it precipitates the molybdic acid. The black oxide seems to be obtained by the action of carbonaceous matter on molybdic acid at a high temperature. The degrees of oxidizement which produced the blue oxide and the acid, are those which can be obtained with most certainty; in all of them the oxygen appears to be retained by a weak affinity. Bucholz, from the oxidation of the metal by heat, and by re-agents, concludes that the following oxides exist, the grey, brown, blue, bluish-green, yellow, and white, the last, indeed, being rather an acid.

From the difficulty of procuring metallic molybdena, the actions exerted on it by the acids are very imperfectly known. Nitric acid acts on it with rapid effervescence, communicates to it oxygen, and converts it first into the blue oxide, and ultimately into molybdic acid. Wilm remarks, that by boiling in concentrated sulphuric acid it is dissolved, communicating to the acid a bluish green colour, which, however, by longer boiling almost entirely disappears, probably from the more perfect oxygenizement of the metal, and its consequent conversion into molybdic acid. Muriatic acid does not act on the metal, but oxy-muriatic acid changes it into the blue oxide. The brown oxide, in being acted on by the acids, is changed into the blue. The transitions of molybdena from the state of the blue oxide to the acid, and of the acid to the oxide, take place from such slight changes of circumstances, as from slight variation of temperature or concentration, that the proper salts of molybdena, or those formed of the oxide and the different acids, are not

easily obtained pure and insulated, and have not been examined. In general they are of a blue colour in the state of solution, but they can scarcely be crystallized without decomposition.

The blue oxide of molybdena, according to Bucholz, is soluble in water, forming a solution of the same colour, which by evaporation becomes of a deep grey; and when cold, of a bluish green. According to the same chemist, it reddens blue paper, and this even more powerfully than what has been named the Molybdic acid; and it produces a brisk effervescence in acting on alkaline carbonates, forming with the alkali a blue solution.

The molybdic acid is obtained by the processes already described, in the state of a yellowish-white powder; the specific gravity of which is 3.4. Its taste is sharp and metallic: it is soluble in water, requiring, according to Mr Hatchet, 960 parts at 212° for its solution: the solution is of a pale yellow colour, has little taste, but changes the infusion of litmus red. Exposed to heat, it is fused: the vitreous matter obtained by cooling, displays a crystalline structure: if heated strongly in an open crucible, it is volatilized, and the vapour, when condensed, forms a scaly powder of a yellow colour. It is decomposed by being heated with carbonaceous matter, and is partially de-oxidated, as has already been observed, by a number of the metals, and by inflammable substances, being reduced generally to the state of the blue oxide. Paper, immersed in the solution, acquires a rich blue colour by exposure to the solar light. Bucholz concluded from his experiments, that 100 parts of molybdena absorb 48 of oxygen in passing to the state of

acid ; and therefore, that 100 parts of this acid, consist of about 77 of metal, and 33 of oxygen.

This acid has relations to the other acids somewhat peculiar. Sulphuric acid dissolves it in considerable quantity, with the assistance of heat, one ounce dissolving ten grains. The solution is colourless, but, as it cools, it becomes of a blue colour, from a change, Mr Hatchet suggests, in the state of oxygenizement of the two acids. Muriatic acid, when digested on molybdic acid, with a strong heat, likewise dissolves it ; the solution being of a pale yellowish-green colour : when saturated with potassa, it becomes blue. Nitric acid has no effect on molybdic acid when digested with it. Sulphuretted hydrogen partially de-oxidizes it.

This acid combines with the alkalis, but the salts resulting from these combinations have scarcely been examined. By combination with a portion of potassa, not sufficient to saturate it, it becomes more soluble in water : its saturated solution in boiling water affords, on cooling, small irregular crystals : it is less volatile than the pure acid. The acid disengages carbonic acid from the alkalis. From Mr Hatchet's experiments, it appears, that, in entering into these combinations, a portion of the acid passes to the state of the oxide, a flocculent matter, convertible into molybdic acid by nitric acid, being deposited as the solution proceeds : on evaporation, more of this matter was separated : no crystallizable compound could be obtained with the compound with potassa. From that with soda, crystals of the form of four-sided tables were formed. From that with ammonia, a striated yellowish mass was obtained by evaporation,

which dissolved again in water, without leaving any residuum. By exposure to heat, this ammoniacal molybdate is decomposed, the ammonia being expelled, and the acid being partially reduced. From these salts, prussiate of potassa does not throw down any precipitate; but if the alkali be super-saturated by an acid, it gives a reddish-brown precipitate. Muriate of tin added to their solutions, produces a white precipitate, which becomes blue when a little muriatic acid is added*.

Molybdic acid, in its action on the metals, is always decomposed, and reduced, in part at least, to the state of oxide. Scarcely any thing is known as to the results which might be obtained from presenting it to the metals previously oxidized. By adding solutions of the alkaline molybdates to the solutions of different metallic salts, the molybdic acid is precipitated, combined with the metallic oxide, and, by this method, several rich colours are obtained. That obtained from muriate of tin is a fine blue, and has been proposed to be fixed in cloth as a dye, the colour being very durable. The molybdates added even to the vegetable dyes, appear to add to the permanence of their colours†.

Molybdena combines with sulphur, and produces a substance analogous to the native sulphuret. A similar compound is obtained by heating the molybdic acid with sulphur, sulphurous acid being disengaged. Pelletier found also that it could be combined with phosphorus; the com-

* Philosophical Transactions, 1796, p. 327.

† Philosophical Magazine, vol. xv. p. 15.

pound not being very different in appearance from the metal itself.

Molybdena combines with a number of the other metals. A series of experiments was made by Mr Hielm on the effects produced by the molybdic acid on metals at a high temperature, and afterwards, what is a more unexceptionable method, on the results obtained by exposing to the heat of a forge reguline molybdena with the different metals. With platina, an alloy was formed of a close texture, of a light grey colour, and metallic lustre, and fusible. With gold, the combination was much less perfect. With silver, when the proportions were equal parts, an alloy was formed of a granular texture, and brittle : with a larger proportion of silver, the compound was malleable, but not easily brought into perfect fusion. The amalgamation with quicksilver could not be effected. The alloy with copper, when in equal proportions, was brittle, paler than copper, but with a lustre not liable to tarnish. Of all the metals, iron, this chemist remarked, unites with molybdena with most facility, and in greatest quantity ; the alloy, from equal quantities of them, was of a bluish-grey colour, brittle, having a granulated texture, and not easily fused into a perfect button. Lead combines with about one-tenth of molybdena, acquires greater hardness and a whiter colour. With tin, it unites in various proportions, and alloys are formed, brittle, more or less soft, and of a dark grey colour. With zinc, a black spongy mass is formed, not easily fused into a metallic button. Nickel and molybdena, fused in equal quantities, form an alloy of a light grey colour, granulated, hard, and brittle. Cobalt like-

wise melts with it, and forms a brittle alloy of a bluish-grey colour. The alloy with manganese is not easily melted into a metallic globule. Bismuth, by an alloy of molybdena, acquires a closer texture, and a black colour: the alloy is also very brittle. With arsenic a black spongy mass is formed. None of these alloys seem to be applicable to any useful purpose*.

CHAP. XXIII.

TUNGSTEN.

UNDER the name of Tungsten, a substance was known to mineralogists, which Scheele discovered to contain a peculiar metal, existing, as he supposed, in the state of an acid united with lime. The same metallic matter was afterwards discovered by Messrs D'Elhuyart, Spanish chemists, united with iron and manganese in another mineral, named Wolfram. These two native productions are therefore the ores of one metal, to which the name of Tungsten has been appropriated. From subsequent researches, it appears that the metal exists in both of them in the state of an oxide, and that the tungstic acid does not even exist.

From the first of these ores the tungstic oxide is extracted by digesting the ore, reduced to a fine powder, in three parts of nitric acid; a yellow powder remains,

* Crell's Chemical Journal, vol. iii. p. 352.

which, after having been washed with water, is digested with ammonia, by which a portion of it is dissolved. These alternate digestions are repeated: the ammoniacal liquors consist of the tungstic oxide, combined with the ammonia: it is precipitated by adding nitric acid to saturate the alkali, is again washed with water, and exposed to a moderate heat, to drive off any ammonia that may remain combined with it. From wolfram the oxide of tungsten may be obtained, according to the method of D'Elhuyart, by digesting it with muriatic acid, which dissolves the iron and manganese: the yellow powder which remains, is then treated with ammonia, as in the preceding process: to the ammoniacal solution nitric acid is added to saturate the ammonia: the oxide of tungsten is precipitated, or is obtained in still larger quantity by evaporating the whole to a dry mass, and calcining this under a muffle, by which the nitrate of ammonia is dissipated.

The oxide of tungsten was reduced by these chemists to the metallic state, by exposing it, moistened with oil, in a crucible lined with charcoal, to an intense heat. After two hours a piece of metal, weighing 40 grains, and only slightly agglutinated, was found at the bottom of the crucible. Klaproth and some other chemists since have been unable to effect this reduction, or at least to fuse the metal completely. Yet it has been obtained in a more or less perfectly agglutinated state by others. Ruprecht, by a process similar to the preceding one, procured it in small metallic globules *. Guyton obtained it in

* Crell's Chemical Journal, vol. iii. p. 301.

a well-fused mass *; and it has also been obtained by Messrs Aikin and Allen †.

Tungsten, in its metallic state, is described by the Spanish chemists as of a greyish-white colour, with considerable brilliancy, brittle and very hard. They state its specific gravity so high as 17.6, so that in this property this metal would stand next to gold: this appears to be confirmed by the experiments of Aikin and Allen, from which its specific gravity is stated at 17.22. Yet by other chemists it is found much lower: that obtained by Ruprecht was found to be not higher than 6.823; and that by Guyton, even when it had been perfectly fused, not more than 8.3406,—a discordance which affords a proof of our very imperfect knowledge with regard to this metal.

The great infusibility of this metal is apparent from the preceding account of the processes employed to obtain it. It appears to be very susceptible of oxidizement, as its surface tarnishes when heated in contact with the air, and a quantity of oxide is formed.

Scheele supposed that the white powder, which is obtained by digesting muriatic or nitric acid on tungsten, adding ammonia to the residuum, and then neutralizing this ammoniacal liquor with nitric acid, as already described, is the pure acid of tungsten. Its acid powers are indeed undoubted: it is very soluble in water, requiring not more than 20 parts at 212° for its solution: its taste is acid, and it reddens the infusion of litmus: it also sa-

* Nicholson's Journal, 4to, vol. iv. p. 191.

† Philosophical Magazine, vol. xii. p. 407.

turates the properties of the alkalis, and forms with them crystallizable salts *. But, according to the Spanish chemists, this substance is a triple compound of oxide of tungsten, and of the acid and alkali employed in the process; nor does there appear to be such a substance as tungstic acid, the product of the highest degree of oxygenizement being only the yellow oxide. This view has been confirmed by a series of experiments made by Vauquelin and Hecht †. The white powder, considered by Scheele to be acid of tungsten, they proved, by analysis, to be always a triple salt; and it is only the yellow powder, obtained by boiling this in a concentrated acid, that is pure. It has no acid property; is quite insoluble in water; tasteless, and produces no change in the vegetable colours; and although it is capable of combining with the alkalis, this is common to it with many metallic oxides. It is obtained pure by boiling an acid on the white powder obtained by the process of Scheele, and exposing the yellow powder, which is thus precipitated, to a red heat; or by digesting wolfram in nitric acid, dissolving the yellow powder that remains in ammonia, evaporating this ammoniacal solution to dryness, and expelling the ammonia from the dry mass by raising the heat: the residuum is the yellow oxide of tungsten. It appears to contain about 0.20 of oxygen. By a strong heat it is partially de-oxidized, and assumes a green colour: when fused with borax, or phosphate of ammonia, it gives a blue tinge, and a rich blue colour is produced when iron,

* Scheele's Essays, p. 289.

† Journal des Mines, No. xix. p. 19.

zinc, or tin, is immersed in the solution of its triple salts, and a few drops of muriatic acid added. It does not change its colour by exposure to light.

Tungsten was found by Messrs D'Elhuyart insoluble in sulphuric, nitric, or muriatic acid. Ruprecht found, that even nitro-muriatic acid boiled on it, did not dissolve any sensible quantity. Nor is its oxide apparently much more soluble in the acids, as is apparent from the processes by which it is extracted from its ores; and Vauquelin found, that even by boiling it with the acids, scarcely any sensible quantity was dissolved. It combines with more facility with the alkalis, at least when a portion of acid is present, and forms soluble ternary compounds.

It does not appear to form any combination with sulphur.

The Spanish chemists sought to discover the results of its combinations with the other metals, by exposing these metals, and the oxide of tungsten, to a strong heat. Gmelin made a series of similar experiments, and, by adding to the mixture a little charcoal powder, rendered the reduction of the oxide more certain. They present, however, no interesting results; and, indeed, in almost all of them, from the extreme infusibility of tungsten, the combinations were difficult and imperfect; and the uncertainty of the metal having ever been obtained pure, renders such researches of little value.

Guyton has found that the oxide of tungsten gives great permanence to the vegetable colours.

CHAP. XXIV.

TITANIUM.

THE metal to which this name is given, exists more abundantly in nature than some of the other newly discovered metals. Mr Gregor first discovered, in a kind of ferruginous sand found in the vale of Menachan in Cornwall, what appeared to him to be the oxide of a new metal, which he attempted in vain, however, to reduce to the metallic state *. Klaproth, some years afterwards, in submitting to analysis a fossil which had been known to mineralogists by the name of Red Schorl, discovered it to be the oxide of a metal until then unobserved, and to which he gave the name of Titanium †. Analysing afterwards the menachanite of Cornwall, he recognised in it the same oxide ‡ : it has since been discovered in other fossils ; and there are now admitted several mineral species belonging to this metal.

The reduction of oxide of titanium to the metallic state is extremely difficult. Vauquelin and Hecht, in their experiments on this metal ||, obtained only an imperfectly agglutinated mass, in which were minute metallic globules. This mass, and the globules it contained, were of a

* Journal de Physique, 1791.

† Analytical Essays, vol. i. p. 200.

‡ Ibid. p. 499.

|| Journal des Mines, No. xv p. 10.

yellowish-red colour, with shades of purple, and other hues. Lampadius appears to have obtained it in more perfect fusion. Its colour was a copper red, with much metallic brilliancy, but liable to tarnish from exposure to the air: it was brittle *. From the experiments of Vauquelin, it appears to be volatilized in intense heats.

It appears to be susceptible of oxidizement without much difficulty, as the metallic mass in which it is obtained, when its oxide is reduced, changes its colour when heated in contact with the air, assuming tints of purple and blue. In the native red oxide, the metal appears to be in a higher state of oxidizement, and it can be oxidized still more highly by fusing it with potassa. On dissolving the fused matter, a white substance precipitates in a short time, which, according to Vauquelin and Hecht, is an oxide containing 0.11 of oxygen.

Titanium is not much acted on by the acids; and its native red oxide, Klaproth found to be insoluble in the sulphuric, nitric, muriatic, and nitro-muriatic acids, even when they were digested on it a considerable time. But when this oxide is fused with six times its weight of carbonate of potassa, it appears, from the experiments of Vauquelin, to absorb more oxygen, and to combine with carbonic acid; and the oxide, in this compound, is soluble in acids, the carbonic acid being disengaged with effervescence.

Sulphuric acid, boiled on titanium, oxidizes and dissolves a small portion of it. When added to the carbonate obtained by the process just now described, it disengages

* Nicholson's Journal, vol. vi. p. 62.

the carbonic acid, and forms, with the oxide, a solution, which, on evaporation, becomes gelatinous. Nitric acid has scarcely any action on the metal or on the red oxide, but, when boiled on the carbonate, it dissolves the oxide which it contains, and the solution, by spontaneous evaporation, affords rhomboidal crystals; by boiling, it becomes turbid. Muriatic acid acts readily on metallic titanium, and dissolves it: it combines also with the oxide of the artificial carbonate: the solution, when heated, becomes gelatinous, or flocculent, and transparent crystals form in it when cooled: when boiled, oxymuriatic acid gas is formed, and a considerable quantity of white oxide is separated from the combination. Phosphoric and arsenic acids were observed by Klaproth to separate oxide of titanium from the other acids, producing compounds which are insoluble, and which are thrown down as white precipitates. Mr Chenevix observed, that these are re-dissolved by muriatic acid, but not by any other.

The salts of titanium give white precipitates on the addition of the three alkalis or alkaline carbonates. Prussiate of potassa produces a green precipitate, but this colour, according to Lowitz, is owing to the presence of iron; the colour with pure titanium being a brownish-yellow: tincture of galls gives a brownish-red. The metals, immersed in their solutions, produce a partial de-oxidizement, which gives rise to various changes of colour: zinc changes the colour from a yellow to a violet, which passes to indigo: tin produces first a pale red tint, which deepens to a bright purple red.

The fixed alkalis, fused with the red oxide of titanium, cause it to pass to a higher degree of oxidizement, as has

been already explained. When melted with borax, it forms a glass of a hyacinthine colour.

Titanium does not appear to combine with sulphur. Its solutions are not decomposed by sulphuretted hydrogen; hydro-sulphuret of potassa throws down from them a precipitate of a brownish-red colour. Mr Chenevix combined it with phosphorus, by exposing to a very violent heat phosphate of titanium, mixed with charcoal and borax, in a double crucible luted. The phosphuret was of a pale white colour, with some lustre, brittle, and of a granular texture, and not very fusible.

The combinations of titanium with the other metals are scarcely known. In the experiments of Vauquelin and Hecht, in which they exposed to heat several metallic oxides with oxide of titanium, and a little oil and charcoal, no perfect combination appears to have been established, except with iron. This alloy was of a grey colour, with metallic particles, brilliant, and of a golden colour intermixed.

Oxide of titanium was used, previous to the discovery of its nature, to give a brown or yellow colour in painting on porcelain; but it was found difficult to obtain a uniform shade, probably from the intermixture of oxide of iron in the native oxide. The pure oxide, obtained by an artificial process, might be used with advantage.

CHAP. XXV.

URANIUM.

THE discovery of this metal is due to Klaproth. A mineral had been known by the name of Pechblende, respecting which different conjectures had been formed. Klaproth, by its analysis, demonstrated that it contains a new metal, to which he gave the name of Uranium. He afterwards discovered that the same metal exists in other minerals, particularly in the state of oxide, in what had been named Green Mica, and in another, which has since received the name of Uranitic Ochre. It is from his experiments principally that our knowledge of the properties of this metal are derived *. He found the reduction of the oxide of uranium extremely difficult. By forming it into a paste with oil or wax, and exposing it in a charcoal crucible to the intense heat of a porcelain furnace, estimated at 170° of Wedgwood, he obtained in one experiment only an aggregate of metallic grains; in another a metallic button. From this last, some of the properties of the metal were determined. It was of a dark grey colour, with a metallic lustre, was hard, of a fine grain in the fracture, and had considerable cohesion. Its specific gravity was 8.1.

This metal is even more infusible than manganese, as a

* Analytical Essays, vol. i. p. 476.

perfect reduction of oxide of manganese to the reguline state was obtained in a heat, in which the uranium, though reduced, was very imperfectly agglutinated.

Uranium does not appear to be very susceptible of oxidizement, as, when small portions of the metal were exposed on charcoal to the flame of the blowpipe, it suffered no change.

The oxide can be obtained by causing the acids, particularly the nitric or nitro-muriatic, to act on the ores of the metal, and precipitating it by the addition of the pure alkalis. It is of a yellow colour, is insoluble in water : when raised to the temperature of ignition, it acquires a brownish-grey colour.

The action of the acids on the metal has not been examined. Klaproth only observed that nitric acid is decomposed by it, and the metal is dissolved. He made several experiments, however, on the saline combinations formed by the action of the acids on the oxide.

By diluted sulphuric acid, assisted by a gentle heat, it was soon dissolved ; the solution by evaporation affording prismatic crystals of a lemon-yellow colour. Nitric acid diluted, dissolved it also readily ; the solution on evaporation affording crystals in large hexagonal tables of a light green colour, and transparent, but liable to some alteration from exposure to the air. The solution of it in muriatic acid, afforded also by evaporation and rest, crystals in rhomboidal tables of a yellowish-green colour. Phosphoric acid dissolves the oxide. but the solution, after some time, deposits pale yellow flocculi, which are the phosphate, and sparingly soluble in water.

The alkalis throw down the oxide from the solutions

of these salts, of a lemon-yellow colour ; with the alkaline carbonates, the precipitate inclines more to white, and is re-dissolved on an excess of the carbonate being added. The pure alkalis do not re-dissolve the oxide, but after some time change its colour to a brown. Prussiate of potassa throws down from these solutions a deep brown-red precipitate ; sulphuret of ammonia, one of a brownish-yellow colour ; tincture of galls, only a small quantity of a blackish precipitate ; but, on the farther addition of an alkali, the precipitate is copious, and of a chocolate brown. The solutions are not altered by the metals, not even by iron or zinc, which proves the strong attraction exerted by uranium to oxygen.

On mixing the yellow oxide with twice its weight of sulphur, and exposing it to heat in a retort, the greater part of the sulphur was volatilized, but a portion remained combined, forming a compact mass of a deep brown colour, from which, however, by again exposing it to heat, the greater part of the sulphur was expelled.

No experiments have been made on the combinations of uranium with the other metals. Its oxide appears, from Klaproth's experiments, to combine with vitrifiable substances, and gives to them a brown or green colour. Fused on porcelain by the usual flux in the enamelling furnace, he found it to give an orange-yellow colour.

CHAP. XXVI.

COLUMBIUM.

MR HATCHET, in examining some minerals in the British Museum, observed one which attracted his attention, from its resemblance to chromate of iron. On analysing it, he found it to be composed of a metallic acid, united with oxide of iron; and this acid, by farther experiments, was found to differ in its properties from every other. Mr Hatchet did not succeed in reducing it to the metallic state. To the metal, however, which he supposed to be its basis, he gave the name of Columbium, as the ore affording it was the produce of America. Little was known respecting the origin of the specimen of the ore found in the British Museum, except that it had been sent to Sir Hans Sloane, with other iron ores, from Massachussets; and as its locality is unknown, our knowledge with regard to the properties of this substance is entirely derived from Mr Hatchet's experiments*.

The mineral which afforded this metallic acid is of a dark brownish-grey colour: its lustre is vitreous, inclining to metallic: its fracture imperfectly lamellated: it is moderately hard and very brittle: its particles are not attracted by the magnet: its specific gravity is 5918.

From this mineral Mr Hatchet extracted the peculiar

* Philosophical Transactions, 1802.

matter which may be named Columbic Acid, by mixing it in powder, with five times its weight of carbonate of potassa, and exposing the mixture to a strong red heat in a silver crucible. On adding water to the mass when cold, a considerable part was dissolved, a brown substance remaining undissolved. Nitric acid, added to the watery solution, produced a copious flocculent white precipitate. On digesting the residuum with muriatic acid, a portion of oxide of iron was extracted: the residual matter of this operation being treated, as before, with the alkali, again afforded a solution with water, from which a white precipitate was thrown down by nitric acid; and by five repetitions of these operations, the whole of the ore was decomposed, and the oxide of iron and columbic acid obtained apart: 42 grains of the former, and 155 of the latter, were obtained from 200 grains of the mineral.

The columbic acid thus procured, is of a pure white colour, and not extremely heavy: it has scarcely any taste, nor does it appear to be soluble in boiling water, but, when placed on litmus paper, mixed with distilled water, soon renders the paper red. When exposed to a strong heat for an hour and a half, imbedded in charcoal, with the view of effecting its reduction, the oxide was found, at the end of the operation, in a pulverulent state, having from white become perfectly black; and even by an intense heat, which melted the crucible, no metal was obtained. When heated by the blowpipe in a platina spoon, or on charcoal, it does not melt, but only becomes of a less brilliant white. Exposed to heat with borax, it remains equally infusible, but, when heated in a platina spoon with phosphate of ammonia, a mutual action, at-

tended with considerable effervescence, takes place, and a globule is obtained, which when cold is of a deep blue, tinged with purple : when held between the eye and the light, it appears of a greenish-grey colour.

This substance is perfectly insoluble in nitric acid, and remains unchanged, even when the acid is boiled on it. It is dissolved by boiling sulphuric acid, and forms a transparent colourless solution, which is decomposed by water, becoming milky on dilution in a few minutes, and depositing a white precipitate, which as it dries changes to a blue, and when completely dry becomes of a brownish-grey. It is then insoluble in water, tasteless, semi-transparent, and breaks with a vitreous fracture. The liquid from which the precipitate has fallen, still retains a little of the original matter dissolved with an excess of acid. Muriatic acid, boiled on columbic acid, or oxide, likewise dissolves it, and this solution may be considerably diluted with water without any decomposition. When evaporated to dryness, a pale yellow matter is obtained, which is not soluble in water, and is dissolved even with great difficulty by muriatic acid. Phosphoric acid, added to the solution in sulphuric or in muriatic acid, produces a copious flocculent precipitate, which, with the sulphuric solution, becomes gelatinous in a few hours.

From the acid solutions of columbic acid, the alkalis throw it down in the form of a white flocculent precipitate. Prussiate of potassa changes the colour to an olive-green, and a precipitate of the same colour is gradually formed. Tincture of galls produces a deep orange-coloured precipitate, especially when there is not too great an excess of acid present. Zinc immersed in the solution,

gives rise to a white precipitate,—a proof of the strength of affinity with which the base of this acid retains oxygen.

The fixed alkalis combine, both in the humid and in the dry way, with columbic acid. When fused with it, a compound is formed, which is soluble in water; and if the alkali be in the state of carbonate, the carbonic acid is disengaged during the fusion with effervescence. When a solution of potassa is boiled on it, a quantity is dissolved; the solution, which has a considerable excess of alkali, affords, by gentle evaporation, a white salt in shining scales, having a disagreeable acrid flavour, not soluble very readily in cold water, but, when dissolved, the solution was permanent. Nitric acid added to it precipitates the columbic acid. Prussiate of potassa and tincture of galls produced no change; but when with either of them a few drops of muriatic acid were added, precipitates similar to those produced by these re-agents in the acid solutions, appeared,—an olive green with the one, and an orange-coloured precipitate with the other. Hydro-sulphuret of ammonia produced a reddish-brown precipitate.

The part of the columbic acid which remains undissolved by the alkaline solution, is not soluble in a new quantity, but becomes in part soluble again, after it has been boiled with nitric acid; and in this manner, by the repeated action of the acid, the whole is rendered soluble in the alkali. This appears to prove, that the portion which is undissolved is in a different state of oxidizement from that with which the alkali combines.

This acid cannot be combined with ammonia.

Columbic acid, when distilled with four parts of sul-

phur remained in powder, and from white, was only changed to a pale ash-colour.

The compound formed by adding phosphoric acid to it, and evaporating to dryness, being mixed with charcoal, and exposed to the heat of a forge, formed a spongy matter of a dark brown colour, somewhat resembling phosphuret of titanium.

There can be no doubt that this substance is possessed of properties different from any of the known metals, or metallic oxides or acids; for although in some qualities it approaches to titanium, tungsten, or to molybdena, it differs from them, and from all the others, particularly in the precipitates it affords with prussiate of potassa and tincture of galls, in not combining with ammonia, and in being insoluble, and unalterable with regard to colour by nitric acid.

CHAP. XXVII.

TANTALIUM.

THE metal to which this name has been given, has been discovered by Mr Ekeberg, a Swedish chemist, in two minerals found in Sweden, which he has named Tantalite, and Yttrotantalite. The first is an alloy of this metal with iron and manganese. The second consists of this new metal, with iron, and a portion of the lately discovered earth named Ittria.

The processes are not distinctly given by which this

metal was extracted from these ores, but it appears to have been by the action of the fixed alkalis at a high temperature; the alkali combining with the oxide of tantalium, and forming a compound soluble in water, from which the oxide is precipitated by the addition of an acid. When separated from the liquid by filtration, and dried, it is in the form of a very white powder, the specific gravity of which is 6.500. When this is exposed to a strong heat with powder of charcoal, it is reduced to a moderately hard globule, having a metallic lustre at its surface, but a dull fracture of a greyish-black colour. The acids have no other effect on this metallic matter, than to bring it again to the state of white oxide: in whatever quantity they may be added, they do not dissolve it. This oxide, or that which is obtained by the action of an alkali, and which appear to be the same, does not change its colour even in a red heat. It melts before the blowpipe with borax, or phosphate of soda, but gives no colour to either of them. The fixed alkalis dissolve it in considerable quantity, but it is altogether insoluble in any acid. This description of the chemical properties of this substance is very imperfect, and would require to be extended by other researches. Ekeberg himself points out some properties in which it resembles tungsten, particularly in the oxides of both being soluble in the fixed alkalis, and insoluble in acids. But the oxide of tungsten is soluble in ammonia: it is rendered yellow by acids; and it communicates colours to borax and phosphate of soda. The oxide of titanium, which has some resemblance also to oxide of tantalium, is at once distinguished from it by being soluble in the acids, after it has been acted on by alkalis, and in communicat-

ing a yellow colour to borax. Both tungsten and titanium are distinguished from it, too, by their very difficult reduction and fusion *.

It has lately been stated, that tantalium has been found by Gahn to be only tin combined with an earth, which he had not ascertained †.

CHAP. XXVIII.

GERIUM.

A FOSSIL found at Bastnaës in Sweden, and regarded as a variety of wolfram, had been analysed by Scheele and D'Elhuyart, but without any certain results. The former chemist not obtaining tungsten from it, named it False Tungsten. It was submitted to chemical examination by Messrs D'Hesinger and Bergelius, two Swedish chemists, and the result was the discovery of a new metallic oxide, the properties and combinations of which they have described in a memoir ‡. The same mineral had been operated on by Klaproth, who extracted this oxide from it; but he considered it as an earth, to which he gave the name of Ochroites §. Vauquelin has more late-

* Journal of the Royal Institution, vol. i. p. 251.—Nicholson's Journal, 8vo, vol. iii. p. 251.—Journal des Mines, No. 70. p. 257.

† Philosophical Magazine, vol. xxviii. p. 307.

‡ Nicholson's Journal, vol. ix. p. 290.

§ Ibid. vol. viii. p. 207.

ly, and with the knowledge of these results, undertaken the examination of this substance; has confirmed the discovery of the Swedish chemists, and even reduced the oxide to the metallic state *. This metal received from its discoverers the name of Cerium; and they also gave the name of Cerite to the fossil in which it is contained. This fossil consists of oxides of cerium and iron, with silice and lime.

The pure oxide of cerium is extracted from the cerite, by dissolving this mineral in nitro-muriatic acid, and, after saturating the clear solution with an alkali, precipitating by tartrate of potassa. The precipitate well washed, calcined, and digested in vinegar, is the oxide of cerium.

After a number of unsuccessful trials to reduce this oxide by Vauquelin, he obtained a few metallic grains, by exposing the tartrate of cerium with lamp-black, oil, and borax, to an intense heat. These did not amount to a fiftieth of the cerium employed; and hence he concluded, that this metal is volatile at a very high heat. They were too minute to admit of any of the properties of the metal being accurately determined.

The oxide of cerium, it is remarked both by the Swedish chemists and by Vauquelin, exists in different degrees of oxidizement. When precipitated from its acid solutions by the alkalis, it is white, but acquires a shade of yellow when dried in the air, and, when exposed to a continued heat, becomes of a brick-red colour. The white, according to Vauquelin, is the one at the lower degree of oxidizement; but the difference in the proportion of oxygen is,

* *Annales de Chimie*, tom. liv. p. 28.

he remarks, inconsiderable. Neither of them can be fused by heat. Borax determines their fusion: the globule, heated by the exterior flame of the blowpipe, is of a blood-red colour, which, by cooling, becomes of a yellowish-green, and at length colourless and transparent, or, if the proportion of oxide has been large, opaque and pearly.

The metal itself, in the trials which Vauquelin made with it, proved insoluble in any unmixed acid, and was dissolved with great difficulty in nitro-muriatic acid. Its oxide, however, combines with the acids easily, and the properties of its salts have been fully determined.

The oxide, at the minimum of oxidizement, dissolves easily in sulphuric acid: the solution is colourless, or of a very light-red tinge, of a sweet taste, and by evaporation affords white crystals. When the oxide is at the maximum, it is dissolved with more difficulty: it requires the aid of heat, and dissolves more readily when the acid is diluted with from 4 to 7 parts of water, than when it is concentrated: the solution is of an orange colour, and by evaporation affords small prismatic crystals of the same colour. In re-dissolving these crystals in water, they are partly decomposed, and a white powder precipitated, which is a sub-sulphate of cerium, while a super-sulphate remains in solution, which by evaporation may be obtained in small prisms.

Nitric acid unites easily with the white oxide of cerium: the solution has a sweet taste, with a degree of sharpness: it does not easily crystallize. The acid dissolves the red oxide with difficulty in the cold, but with heat more easily: the solution is of a yellowish-green colour. If there be an excess of acid, white crystals are obtained.

on evaporation and cooling, but the neutral solution becomes only of a thick consistence by evaporation : alkohol dissolves this matter, forming a red-coloured solution.

The red oxide of cerium is slowly dissolved by muriatic acid in the cold, and more readily by heat ; and oxymuriatic acid gas is formed and disengaged with effervescence. The colour of the solution is a faint greenish-yellow ; evaporated to the consistence of honey, it affords a confused crystallization ; the saline matter is deliquescent ; it is soluble in its weight of cold water, and in three or four times its weight of alkohol. It is decomposed by heat, oxymuriatic acid being disengaged ; and if iron be present, it is sublimed in the state of muriate.

Phosphoric acid digested with oxide of cerium, forms an insoluble salt. It combines with carbonic acid, when water saturated with that acid is poured on it ; and when humid, it attracts carbonic acid from the atmosphere. The compound is insoluble. Both the phosphate and carbonate are likewise easily formed by complex affinity.

The salts of cerium are decomposed by the alkalis, and a precipitate thrown down, which appears to be a subsalt. If an excess of acid be present, triple salts are even formed. The saturated solutions of cerium are precipitated white by prussiate of potassa. Gallic acid gives a very small quantity of a white precipitate, which is increased, and becomes brown when an alkali is added. Hydro-sulphuret of ammonia produces a brown precipitate ; and a deep-green one when a larger quantity of the hydro-sulphuret is added. Hydro-sulphate of potassa forms at first a green precipitate, which, according to Vauquelin, arises from the presence of iron : when this

has subsided, and a fresh quantity of the hydro-sulphuret is added, the precipitate is white, similar to that by the alkalis : it appears to contain no sulphuretted hydrogen, as it dissolves in acids without any effervescence ; and hence the oxide of cerium does not appear to combine with sulphuretted hydrogen, nor to be reduced by it. Phosphorus put into a solution of muriate of cerium throws down gradually a white precipitate. The solutions of cerium are not precipitated by iron or zinc.

The pure alkalis do not dissolve cerium, even by fusion. Ammonia, digested with the oxide, does not dissolve it, but renders it yellowish. The carbonated alkalis dissolve it in small quantity in the humid way, and likewise by fusion, forming triple salts.

BOOK VII.

OF MINERAL COMPOUNDS.

I HAVE given this name of MINERAL COMPOUNDS to those combinations of Acids, Earths, Metals, and Inflammables, which exist in the mineral kingdom. And with regard to these, I have already remarked, under the general statement of chemical arrangement, that there are certain characters belonging to them, by which they are discriminated from the other orders of chemical agents. These, and the point of view under which these substances are to be considered as objects of chemistry, I have to state before proceeding to their individual history.

The peculiarity which exists with regard to these substances, arises from this, that in consequence of their aggregation, or their state of combination, their chemical agencies are extremely weak. They possess few distinctive chemical properties, and exert no important chemical actions. And even to discriminate them from each other, it is often necessary, not only to attend to properties which are strictly chemical, but to call in the aid of physical qualities; by the minute shades of which not unfrequently are these discriminations established.

Hence the connection which has always existed between Mineralogy and Chemistry. As a material sub-

stance, every fossil is necessarily an object of chemical science: it must be subjected to the methods of analysis: if compound, its composition determined; and whatever may be its nature, what chemical properties it possesses must be noticed, and the applications to which these may lead pointed out. But in discriminating them from each other, it is necessary, to a certain extent at least, to have recourse to mineralogical description. Each individual substance cannot be analysed: this would be impracticable; and were it not, it would be without utility. But when the analysis of a fossil has been effected, we presume that a similarity of composition will exist in other specimens, which agree with it closely in their external properties or characters; and hence the necessity of an attention to these characters, in regarding the substances of the mineral kingdom as subjects of chemical investigation.

It is under this point of view that Mineralogy ought to be regarded in its relation to Chemistry. The object of the Mineralogist is to trace all the distinctions, even the most minute, among the substances which are the subjects of his science, and to mark every variety of form and appearance under which a fossil is exhibited. He is therefore led to cultivate, with the strictest attention, the mineralogical method, and the language by which these minute distinctions can be expressed. The object of the Chemist is more general. The composition is what he has more peculiarly to attend to; to discover in each species the composition which forms its basis; and in a great measure to disregard more minute distinctions, farther than what may be necessary to connect the varieties

to which these give rise, with the species which analysis has determined. Thus chemistry and Mineralogy, in relation to fossils, has each its peculiar province, and the one is calculated to assist and reflect light on the other.

The great difficulty which exists in this department of science, is that of determining what properly constitutes the mineral species : and it is probably only by chemical analysis that this can be determined with certainty. In the animal and vegetable kingdoms, the species is fixed by an invariable character. A certain organization and form are transmitted from one individual to another, with the power of continuing the same succession. On this the species is founded : and although there may be approximations among the various species in the general assemblage of properties, there is no such thing as an imperceptible gradation. The individuals of each not liable to be placed under variations of circumstances at their formation, when the characters are fixed, are not liable to be much disguised in structure or form ; and any alteration, when produced, being confined to the individual, is soon lost.

But in the mineral kingdom the species are not so determinate. Arising from chemical combination, and that combination being liable to be influenced by various circumstances, while there is no power counteracting these, and preserving uniformity, the individuals are liable to be almost indefinitely diversified in their properties, and to pass by insensible gradations into each other. Hence the difficulty of establishing the species of the mineral kingdom, and of forming a mineralogical classification.

Since the time of Cronstedt, who gave the first sketch of what may be termed Chemical Mineralogy, the superiority has been generally allowed to that method which classes minerals according to their chemical relations. On these are founded the great classes of Salts, Earths, Inflammables, and Metals, with their inferior divisions;—the class of salts comprising as genera the various saline compounds found in nature, which are formed by the union of the different acids with different bases; each simple earth giving its name to an order under which are arranged the fossils in which it is predominant, or to which it gives a predominating character; each metal forming a similar division, to which are referred the various native compounds in which that metal is combined; and the few inflammables found in the mineral kingdom being arranged in a similar manner. The formation of the species has been attempted on the same basis; and although, from the difficulty of discovering with certainty what is essential in composition, the method may often, in the present state of our knowledge, be found defective, it is probably founded on just views, and can indeed alone lead to the proper specific distinctions. The chemical composition of fossils is the only thing determinate with regard to them: it is that from which their properties originate, and which gives rise to their essential differences. In the animal and vegetable kingdoms, characteristic properties are stamped by a power peculiar to them as living and organized bodies, and to derive distinctions from any other source would be useless and absurd. But in minerals this is totally wanting; and what

remains to constitute the proper or natural species, but their chemical composition?

The most celebrated modern Mineralogists, however, though admitting the chemical composition as the basis of specific distinction, have deviated more or less from this in the construction of their systems, and have often formed and arranged their species on very different characters. Thus Werner has observed, in the introduction to his *Treatise on the External Characters of Minerals*, that the foundation of the species is an agreement in the relations of the constitution of fossils, defining, at the same time, this *constitution* to be the combination of their constituent principles; yet in establishing his species, he often departs from this principle, different species being formed where there is no essential difference of composition, and minerals being often grouped in direct opposition to chemical arrangement. And Haüy, although admitting, in his definition of a species, the necessity of recognising the chemical composition, places it as subordinate to a distinction drawn from a different source,—the form of the integrant molecule; and, in the details of his system, frequently neglects it when placed in opposition to the character which he thus combines with it.

The source of discordance on this subject, and that which has given rise to a deviation from an acknowledged principle, is the difficulty of determining the chemical composition of minerals with accuracy. From the analyses that have been made, it is found, that substances, which, from their very strict resemblance, not merely in some arbitrary characters, but in the general assemblage of their qualities, appear to belong to one species, often

differ considerably in composition ; while in other cases, substances which differ widely in their qualities, are not very different in their composition.

These circumstances no doubt arise from the modes of chemical analysis being yet imperfect ; and particularly from our being still almost wholly ignorant of what determines the properties of compounds so complicated as minerals generally are. All the ingredients are not to be regarded as equally energetic, or as in the same proportion contributing to the peculiar constitution of a compound ; and if one which, in its relation to others, is comparatively feeble in its action, be present in large proportion, it leads to erroneous conclusions, when, in determining composition, we attend merely to the relative quantities of the principles, without attending to their relative energies. This has been generally hitherto done ; and among the earthy fossils, the predominating principle has always been regarded as that which is present in largest proportion, though the reverse is probably frequently just. An ample field of research is open in relation to this subject, which may lead to interesting results ; and, by attending to what is important, and what is comparatively trivial in a composition, the mineralogical species may be better determined.

Another source of error is in our ignorance frequently of what is chemically combined, and what mechanically blended in a fossil, and likewise often whether a fossil is homogeneous, or rather an aggregate, the parts of which are too small to be perceived as distinct. The state of aggregation, too, disguises the identity of the species ; and by giving origin to different external characters, pro-

bably frequently gives rise to distinctions which are unessential, and which would be subverted by a knowledge of the real composition.

These imperfections of chemical analysis, which will doubtless be only slowly remedied, have rendered it necessary, in framing the mineralogical system, to call in the aid of other characters, and other sources of discrimination, in establishing the species; and the importance of these being naturally somewhat exaggerated by those who have most carefully cultivated them, this has given rise to their too extensive application, and to the departure from principles acknowledged to be just.

In the system of Werner, these characters are taken from the external properties of minerals; the species being frequently formed from a certain assemblage of these properties, independent altogether of their chemical relations.

Of the value of these characters as descriptive, and even of their successful application in many cases in fixing the species, no doubt can be entertained: it may only be questioned, whether they have not been carried in the last respect too far, at least when they are placed in opposition to chemical analysis. The method of fixing the species from the properties of the substances must always be to a certain extent arbitrary and uncertain;—arbitrary, as being dependent on the rules that have been followed in selecting the distinctive characters, so that if different rules were followed, different groupes would be formed;—uncertain, as important diversities of properties may arise in a combination, from circumstances altogether trivial and accidental, and specific distinctions,

drawn therefore from such properties, must in such cases be erroneous. So far as the individuals which are of similar composition are placed together, the system is a natural one; and in the diversity of systems that might be formed, a number of the species, were even the external characters alone to be attended to, would thus be found the same. But this is only from the circumstance, that similarity of composition in general gives rise to similarity of properties; and hence allows, even on the principles on which such systems are constructed, a number of natural species to be formed. But where this is not present, and where the external characters, instead of being regarded as subordinate to the chemical relations, are placed in opposition to them, and considered as the proper basis of specific distinctions, the arrangements, whatever excellence they may possess as descriptive, are artificial, and must, in the progress of the science, be found fluctuating and uncertain.

In the system of Haüy, the chemical composition, though professedly taken into view in forming the species, is in reality equally departed from, and rendered subordinate to another character, that derived from the form of the integrant molecule of the crystal. I have already remarked, under the chapter on crystallization, that in every crystallized substance, a common form exists in all the varieties of its crystals, which may be extracted from these by mechanical separation. Now, from this, in the system of Haüy, the character of the species is in a great measure taken. According to his definition, a species in mineralogy may be said to be *a collection of bodies, of which the integrant molecules are alike, and*

*composed of the same elements united in the same proportions ; this latter condition being added, as Haüy remarks, to generalize the definition, and extend it to substances, which, having their integrant molecules of the same form, differ essentially in the principles of which these molecules are composed ** ; the form, therefore, being the basis of the specific distinction.

This character has likewise been too far extended, instead of being kept in its proper place as an auxiliary to chemical analysis ; and hence the objections to which the system has been rendered liable. The insufficiency of the form of the integrant molecule to determine the species is at once apparent from the admission of the fact, which renders the qualifying condition necessary, that mineral species, totally distinct, have frequently the same primitive form. And although Haüy has remarked, that “the greater number of substances which have a common molecule, are easily distinguished by other characters,” this, independent of the admission implied in it, that the character from the form of the molecule is defective, is no necessary circumstance ; on the contrary, there is no cause why two species very closely allied in their external characters, may not have a similar alliance in the form of the primitive molecule. In such a case, according to this system, we should either be obliged to have recourse to chemical analysis, or to some other character, to distinguish them ; or we must confound, under one species, what are essentially distinct. And accordingly there are several examples in Haüy’s system,

* *Traité de Mineralogie*, tom. i. p. 162.

of a mineral important from its uses, extremely different from others in its external characters, and even in its composition, being ranked merely as a variety, because its difference of form is not regarded as sufficiently important to constitute it a species. It has also already happened, in several instances, that chemical analysis, and the character from the form of the molecule, are at variance ; not only substances which analysis has shewn to be different having the molecule of the same form, but others, proved to be alike, by the most rigid analysis, having a different form. Lastly, a proof of the deficiency of this method equally conclusive is, that many fossils, well characterized as species, do not occur crystallized, and therefore, either cannot be arranged under it, or, in defiance of their real distinctions, must be placed as varieties of other species, which happen to exist in a crystallized state. Still the character, if preserved within its proper limits, as subordinate to the chemical relations, may in many cases be of utility in determining the species. It arises undoubtedly from the chemical composition of the substance. Where, therefore, it is difficult to determine with accuracy what is essential to the composition, what adventitious, assistance may be derived from this character. This I conceive to be its proper limit : Or it ought to be considered as an indication of composition, as subservient to analysis, and as contributing to establish the species on their chemical nature.

The conclusion which may be drawn from the preceding observations is, that the chemical composition is the basis of the mineral species, but that as in a number of cases this cannot be determined with sufficient precision

by our methods of analysis, and in the present state of chemical knowledge, recourse must be had provisionally to other characters, and particularly to those drawn from the properties of fossils. This gives rise, therefore, to a mixed method. Many species may be unequivocally fixed by chemical composition alone. But there are also a number of fossils, with regard to which it is scarcely possible to assign a particular composition as the basis of the species. The specific distinctions of these are drawn from their external properties, a certain assemblage of which is supposed characteristic of one species, and a number of species are thus formed. If I have observed a fossil which differs in the assemblage of its properties from others usually met with, I consider it as a distinct species, and give it a particular name. Suppose it to be the species *Feldspar*: I characterise it by its general properties, its peculiar hardness, specific gravity, lamellated texture, rhomboidal fragments, fusibility, and others. I may also by analysis determine its chemical composition. If another fossil is discovered varying from the former, as for example in colour, but which in the aggregate of its properties is the same; it is still regarded as *Feldspar*. If, on proceeding to analyse it, its composition is even found to be somewhat different from the former, this does not establish the conclusion that it is a different species; on the contrary, the difference is considered as unessential, and it is arranged with the fossil which it resembles in its properties. In this manner, the species are determined as frequently from resemblances in properties as from identity of composition; and even a strict analogy in the former is admitted as sufficient to counterba-

lance a considerable deviation in the latter, and cause different varieties to be arranged under one species, though their composition is not perfectly alike. It cannot be doubted but that thus many natural species are formed, the correspondence in properties which has fixed the species, arising from a uniformity in composition; though it is no doubt equally true that some of them are artificial, and will be blended with the others, as the methods of mineralogy and the mineral analysis are improved.

It is of importance, however, to remark, that the necessity of having recourse to the properties of fossils, as affording specific distinctions, is only with regard to some fossils, and that in the greater number the species may even at present be founded on the chemical composition. Nearly all the metallic species may be determined from this alone, though difficulties may in some instances occur from gradation of composition, or mechanical intermixture. How well defined, for example, as a species, is the carbonate or the phosphate of lead, and indeed all the native metallic salts? The metallic sulphurets are nearly equally capable of being thrown into distinct species from their composition, especially if attention is paid to the metal which is essential to it. The species of at least three earths, lime, barytes, and strontites, are at once fixed from their chemical composition; for who would refuse as species the sulphate of lime, or the carbonate or sulphate of barytes, or of strontites, or search for any other specific distinction than their chemical nature? If I take a specimen of one of these, suppose it to be sulphate of lime, it is in my power to analyse it with accuracy, and therefore I shall always be able to re-

cognise it, whatever appearance it puts on. In one specimen I may find it of a fibrous structure, in another foliated, in a third compact; in some it may be colourless, in others coloured, and in some cases it may be amorphous, in others crystallized. But under all these aspects, and even were the differences greater, it is easy to discover the identity of these specimens by analysis, and hence they are to be regarded only as varieties of one species.

The only fossils with regard to which a difficulty exists, are those which consist of different earths in combination with each other; for with regard to these, not only is the accurate analysis more difficult, but the difficulty is also greater of determining the particular composition which constitutes a species. If I examine, for example, by chemical methods, a specimen of feldspar, I shall find that it always contains, as its principal ingredient, siliceous earth, and next to it argillaceous. But the proportions and the other ingredients are very various: the proportion of silex varies from 60 to 70, of argil from 12 to 17: some specimens contain lime, others none; in some barytes and magnesia are present, but not in others; and, lastly, potassa has been discovered in one variety, without being detected in the rest. Now, it is obvious that from such analyses, even making due allowance for their inaccuracy, it is difficult to determine what peculiarity of composition constitutes the species to which the name Feldspar is assigned. The same difficulty exists with regard to many other fossils, to the same, or to a greater extent.

It arises, as I have remarked, altogether from the imperfections of chemical analysis. In fossils consisting

of a number of ingredients, it must be difficult to determine what are the essential ingredients, or in what modes they are united. It is evident, that every substance extracted from a mineral may not have entered strictly into its composition, but may have existed in it merely in a state of mixture. We have hitherto also discovered little as to the mode in which the principles of these complicated compounds are combined; they may be united in one combination by a balance of affinities, or they may form binary compounds, which are united with each other. Mineral analysis has gone no farther than to determine what are the ingredients of a fossil, and their proportions; the state in which they exist, and their mode of combination, are not of less importance in determining similarity of composition, and investigations directed to these points will undoubtedly facilitate the arrangement of minerals on a chemical basis. These fossils are at present precisely on the same footing with the products of the vegetable and animal kingdoms. Of these a number of species are formed, as gum, resin, sugar, in the one; gelatin, albumen, fibrin, in the other; each of which is undoubtedly founded on a peculiar combination, essential to all the varieties of the species, and the source of the specific distinctions. But, in the present state of chemical knowledge, we find it more practicable to determine the species from the properties of the substance, than from its analysis; though this does not prove but that the composition is the real basis of the species, and the progress of Chemistry will no doubt ultimately discover it in each.

If these observations be just, it must be regarded as a

retrograde step in science to reject the method of drawing the specific distinctions of fossils from their composition, and instead of this, to derive them from their individual properties; for it is neglecting what, where it can be applied, is the only proper basis of the species in inanimate bodies, and preferring what ought to be regarded as subordinate and provisional. The method which appears to be just, is to apply the distinction from composition, where it is applicable; and where it is not, to avail ourselves in the mean time of other characters, and to expect the perfection of the classification in the progress of chemical analysis. Where the species cannot be derived from composition, it undoubtedly must be formed from analogy in properties; and the skill of the Mineralogist has an ample field for exertion in seizing on those analogies which are most distinctive, and most intimately connected with identity of composition. Where a number of varieties agree in the possession of certain distinctive qualities, these ought to be considered at present at least as a species, though the composition which constitutes this may not be fully determined. But where the chemical constitution is unequivocally determined, it is a singular error to disregard this, and establish the species on other characters. The property of establishing the species feldspar or garnet on external characters, is not to be questioned; for, in the present state of chemical analysis, we cannot assign the precise composition on which it is founded. But who can doubt of the composition of sulphate of lime, sulphate of barytes, or sulphate of strontites? Each of these is a proper species: there is no essential difference in composition, whatever difference

there may be in properties, in the varieties of it which exist in nature ; and to form any of these varieties into species, would be to create distinctions without any *essential* difference ; or to derive the species itself from the properties, and not from the composition, is to relinquish a sure criterion, for one which must always be in some degree uncertain and vague.

The species being thus fixed on chemical composition, the genera and orders have necessarily the same basis ; and this method of establishing the higher divisions, has indeed been generally adopted in mineralogical systems. Each metal and each earth gives rise to a genus, and under each genus are arranged, as species, the fossils in which that metal or earth is the predominating ingredient. Even those mineralogists who have most decidedly rejected the chemical system of classification, and endeavoured to establish the species on external characters alone, have been obliged to admit, that these higher divisions can be formed only from chemical relations. They have, for example, placed the ores of each metal as forming the species of one genus, though among these species it is impossible to trace a single character by which they can be connected, or assign any other reason for their being placed together, than their chemical nature. Were this principle not adopted, carbonate of lead, or carbonate of zinc, it is well observed by Haüy, must be regarded as species altogether foreign to the metals, and would undoubtedly, from mere external properties, be placed with many other metallic ores among earthy fossils. And no other principles of arrangement can be followed in the higher divisions, without rendering mi-

neralogy an assemblage of the most arbitrary and fluctuating distinctions.

The method now sketched, assimilates readily with the arrangements of a System of Chemistry, since the basis of the classification is strictly chemical. It is also obvious from these observations, that those minute descriptions of minerals which are proper in a system of Mineralogy, would be misplaced when considered in relation to their chemical history. What is required by the Chemist, is to mark, as fully and distinctly as possible, the proper species of the mineral kingdom, considering these species as resting on chemical composition; and to extend the description of them from their external characters, only so far as is necessary to describe the species with sufficient accuracy to distinguish it from others. These are the objects I shall have in view; adding such observations with regard to the history or uses of fossils, as may be calculated to give interest to a subject, which to those who have not already made it the object of study, is liable to become tedious, when the strictly descriptive method is alone followed. The more full description of minerals, according to the Wernerian method, will be found in the System of Mineralogy by Professor Jameson, or the *Traité Elementaire* of Brochant. The Treatise of Haüy may be consulted for the details founded on his peculiar system.

In concluding these observations on the mineralogical part of this volume, I have thought it may be of some utility to give a general view of the language employed in the descriptions of fossils, as a number of the terms, being understood in a particular sense, require to be de-

fined. For the full exposition of this language, according to the method of Werner, I may refer to his Treatise on the External Characters of Fossils, translated by Mr Weaver, or to the Treatise on the same subject by Mr Jameson; the abstract I have given being such only as I conceived necessary to render intelligible, to those who have no previous knowledge of the subject, the mineralogical descriptions which I have introduced.

Werner has arranged the characters of minerals under four divisions:—the External, the Internal or Chemical, the Physical, and the Empirical. To the first belong the characters drawn from those properties which are obvious to the senses, such as colour, lustre, transparency, form, texture, hardness, and specific gravity; to the second, those which are derived from the chemical composition, or are discovered by any chemical change which the mineral suffers; to the third are referred those characters which are afforded by some important physical properties, as electricity or magnetism; and to the fourth, a few characters derived from some circumstance frequently observed with regard to a mineral, as the place where it is generally found, or the minerals by which it is usually accompanied. Of these divisions, the External Characters are considered as the most important, and it is chiefly with regard to them that so much labour has been employed on the language of Mineralogy. Without following the minute subdivisions under which they have been systematically arranged, I shall consider them in that order which appears most simple.

The first property considered as affording one of the characters of a mineral is COLOUR. Though one of the

most obvious, it is seldom that it is highly characteristic, as in the same species it is often very various, and is liable to be varied too by very trivial foreign circumstances. From assigning too much importance to it, many erroneous distinctions have been introduced, as for example, with regard to the gems, from which the science is not yet entirely free. Still, from being so striking a property, it must in all cases enter into the description. There is, however, considerable difficulty in framing terms which shall convey precise ideas of the different shades of colour. The method which Werner has adopted is to fix on certain principal or standard colours, and to refer to these the subordinate shades, defining them by adding an epithet, either expressive of the intermixture of one of the principal colours with the other, or derived from some substance familiarly known, the colour of which is constant. The principal colours which he has assumed are, *white, grey, black, blue, green, yellow, red, and brown*; and of these are numerous subordinate colours, designated according to the above mode, as *bluish-grey, greyish-black, blackish-green, snow-white, lead-grey, pitch-black, indigo-blue, grass-green, &c.* Even these are not always well marked, but *incline to, are intermediate, or pass* into each other. The shade of colour is also of different intensities,—dark, deep, light, and pale. The discrimination is also often derived from the tarnishing of colours, where the colour of the surface is different from that which a fresh fracture exhibits; or from the play or the changeableness of colours, as the position is varied with regard to incident light. Lastly, numerous varieties are introduced from the delineation of colours, arising from

an assemblage of different colours on the same surface, as dotted, striped, zoned, &c. The colour is also sometimes varied by scraping the surface, affording a character named the **STREAK**.

LUSTRE denotes the relation which a fossil bears to the reflection of light from its surface. The different degrees of it have been expressed by numbers. Werner employs defined terms, which is a preferable method; as with regard to qualities which do not admit of exact measurement, it is difficult to attach precise ideas to arbitrary numbers. In the Wernerian language, *resplendent* denotes the highest degree of lustre, which is such as to be visible even at a considerable distance: *shining* is applied when the lustre, though perceived at a distance, is not so well observed as on a near approach: *weakly-shining* or *glistening*, when it is perceptible only at a very short distance: *glimmering*, when some of the minute parts only of the surface reflect a weak light: and *dull*, when lustre is entirely wanting. Different kinds of lustre are also marked, as the metallic, adamantine, vitreous, waxy, pearly, and resinous.

TRANSPARENCY.—To denote this property in its different degrees, numbers have likewise been employed, but, for the reason already stated, defined terms are preferable. The following were introduced by Werner:—*Transparent*, applied where objects can be distinctly perceived through the interposed substance: *semi-transparent*, where objects are seen, but not distinctly, and this only through thin pieces: *translucent*, when light is in some measure transmitted, but objects cannot be observed: *translucent at the edges*, when the light is transmitted only

through the thinnest edges or fragments : *opaque*, when no perceptible light is transmitted. Connected with the transparency is another characteristic property,—the *Refraction*, which in the greater number of minerals is single, but in some double, the latter of course giving a double image when an object is surveyed through them.

FORM.—This is perhaps the most important of the external characters of fossils. It includes the figures of their crystals, and the various particular forms which many of them, even in their uncrystallized state, often assume. With regard to the first of these,—the forms of the crystals, and the methods by which these are described, sufficient details have been given under the history of Crystallization, in the first volume, to which I refer. The aggregation of crystals affords some distinctions, especially where they form groupes disposed in particular modes, as scopiform or fascicular, where slender crystals diverge from a common centre ; acicular, where long needle-shaped crystals adhere laterally ; manipular fasciform or sheaf-like ; pyramidal, &c.

Of the less regular, or what have been termed the Imitative forms, there are many varieties, named usually from resemblances they have to objects generally known ; as capillary, or in fine threads ; filiform, or like wire ; dentiform, resembling teeth ; reticulated, or like network ; dendritic or arborescent, resembling branches ; coralliform, like coral ; stalactitic, consisting of conical shoots or projections ; botryoidal, resembling a branch of grapes ; reniform, mammillary, cavernous, &c.

The Structure or Texture of fossils, as discovered by their FRACTURE, affords, perhaps, next to form, the most

important of any single discriminating character. The fracture may either present a surface continuous or uninterrupted ; or it may present a surface composed of an aggregation of distinct parts, by which the continuity is more or less broken. The former is named the *Compact*, the latter has been termed the *Jointed Fracture* ; and each is subdivided into a number of varieties. Of the COMPACT, we have,—the *Splintery*, where on a surface, even or nearly so, small splinters or scales are perceptible, adhering to the mass, and so thin at their extreme edges as to be visible by the light transmitted, the scales being greater or smaller, and thus giving rise to the distinctions of coarse and fine splintery :—the *Even*, where the surface is smooth or destitute of elevations, or at least where the inequalities are few and indeterminate :—the *Conchoidal*, where the surface is composed of concave and convex round elevations and depressions, and subdivided, according to the magnitude, into large and small conchoidal, or, according to the appearance of the elevations and depressions, into perfect and imperfect conchoidal, or into deep and flat :—the *Uneven*, in which the continuity of the surface is interrupted by irregular elevations and depressions, rather large and usually angular, forming, according to their size, what are named coarse grained and fine grained :—the *Earthy*, where the surface is rough, from a number of small elevations and depressions : and, lastly, the *Hackly*, presenting small sharp-pointed elevations, and peculiar to the metals. The JOINTED Fracture, which is opposed to the Compact, is subdivided into the Fibrous, the Striated, and the Foliated. The first of these is where a number of parts like lines are discernible, which may be coarse or delicate, straight or curved,

parallel, diverging, or promiscuous. The second, or the *Striated* or *Radiated* Fracture, is that which consists of long and narrow aggregated planes, and differs from the former principally in these planes being of such a size that their surface can be distinctly perceived; being equal in breadth sometimes to one-fifth of an inch, and from this graduating into the fibrous. The striæ are generally pointed at the one extremity, and broader at the other: they also may be strait or curved, parallel, diverging or promiscuous. The last variety of fracture is the *Foliated* or *Lamellated*, which is composed of planes sufficiently distinct, the length and breadth of which are nearly equal. These may vary,—1st, In magnitude; the folia sometimes extending through the whole mass, and from this lessening to very small scales:—2d, In perfection; the fracture being either perfectly foliated, where the folia or plates separate smoothly from each other; imperfectly foliated, where the folia separate unevenly, and with rather less lustre and smoothness than in the preceding; or concealed foliated, where the folia appear only in a few places, and are indistinct:—3d, In direction; the folia being either straight or curved:—and, 4th, In passage or cleavage, by which is meant the property of splitting in certain directions; some fossils splitting only in one direction, when they are said to have a single cleavage; some in two, when they are said to have a double cleavage; some in three directions, in four, or even in six.

The Slaty has been distinguished from the foliated fracture by the parts possessing greater thickness, and not being capable of subdivision into very thin plates, splitting only in one direction, and separating with less smoothness. It forms the transition into the compact.

The form or shape of the Fragments of a Fossil frequently affords a discriminating character, as, in breaking, some fossils give fragments always of the same shape. The form may be regular, as cubical, rhomboidal, pyramidal, and trapezoidal; or irregular, as cuneiform, specular, tabular, or altogether indeterminate.

Another character connected with the structure of fossils, is derived from the appearance of Distinct Concretions which they present, divided by natural interstices or joints, and therefore capable of being separated without breaking the mass; or, if they are more closely aggregated, they are still discoverable by their different positions. With regard to shape, they are distinguished into,—*Granular* distinct concretions, which may be round or angular, large, coarse, small or fine;—*Lamellar* distinct concretions, which may be straight or curved, thick or thin;—*Columnar* distinct concretions, which may also be straight or curved, thick or thin, perfect, imperfect, or wedge-shaped, parallel, diverging, or promiscuous. All of these frequently pass into one another, and two of them are sometimes present in one fossil, the one intersecting or including the other.

HARDNESS.—This is a very important property in discriminating minerals. The degree of it in a fossil is judged of with most certainty by the comparative facility or difficulty of impressing it. Four degrees of it are marked by Werner:—*Hard*, in which the substance is not capable of being scratched by the knife, but, on the contrary, gives sparks more or less plentiful when struck with a piece of steel; it may not yield to the file, when it is said to be extremely hard; or it may yield to it with dif-

difficulty, suffering a slight impression, when it is said to be very hard; or, lastly, it may be scratched by the file without difficulty, when it is said to be hard : *semi-hard*, when it does not strike fire with steel, and may be scraped by the knife : *soft*, when it may be easily scraped with the knife, but receives no impression from the nail : and *very soft*, when it is scratched by the nail. These pass into each other. Häüy follows a different mode : He determines the degrees of hardness according as one fossil impresses another. In one division are placed those which scratch quartz ; the individuals belonging to this being arranged as much as possible in the order of their relative hardness, so that when placed in a column, each is understood to impress those beneath it. In a second division are arranged, in a similar manner, those which scratch glass ; in a third, those which scratch calcareous spar ; and in a fourth, those which make no impression on it, and which, perhaps, might be farther characterized, by being capable of being scraped by the nail.

TENACITY is that property which relates to the cohesion of the integrant particles of solid minerals, which, existing in different degrees, gives rise to the distinctions of brittle, malleable, and the intermediate degree of sectile.

The FRANGIBILITY is different both from hardness and tenacity, and denotes the facility with which a mineral may be broken. It exists in different degrees, which are marked by the common terms of difficultly frangible, easily frangible, &c.

SPECIFIC GRAVITY.—This property is of course determined with most accuracy by weighing with the hydrostatic balance. As this cannot always be practised, Wer-

ner gives different degrees of specific gravity so general, that they may be determined by poising the mineral in the hand. These are *supernatant*, applied to minerals of less specific gravity than water, and which therefore swim on its surface : *light*, the specific gravity of which is between 1000 and 2000 : *rather heavy*, in which the specific gravity is between 2000 and 4000 : *heavy*, where it varies from 4000 to 6000 : and *very heavy*, including all those fossils, the specific gravity of which is above 6000. The degrees of specific gravity are perhaps more easily and accurately conceived, from stating the numbers denoting them in the usual manner.

To these external characters are added a few of less importance, and requiring no particular observations, which are derived from properties peculiar to a few minerals, such as that of adhering to the tongue ; soiling the finger ; feeling hard, or unctuous ; giving a particular streak on paper ; giving, when struck, a peculiar sound ; feeling cold when applied to the tongue ; having taste ; or emitting some perceptible odour.

The Chemical Characters of fossils are less numerous, but they afford very important aid in discriminating them, and in fixing the species.

The Fusibility is generally determined by the action of the blow-pipe, as we can thus operate on a small fragment, and perceive easily the appearances presented on fusion. Some minerals are perfectly infusible by it ; others melt with facility : some fuse with intumescence ; others decrepitate or exfoliate when urged by the flame, or lose their colour ; in some the fusion is partial : sometimes the result is a kind of scoria ; in many cases it is

a complete vitreous globule, transparent or opaque, and of various colours. These appearances are diversified by adding to the substance, which is the object of experiment, various fluxes, particularly borax and the phosphate of soda and ammonia. The volatility of minerals by heat is determined by similar experiments, and attention is paid to the appearance of the vapour, its odour, &c.

The action of acids affords another important chemical character of fossils, by observing whether they effervesce when touched with the acid, or whether, when a small fragment is immersed in it, it is partially or entirely dissolved; if the solution is fluid or gelatinous; and what appearances it presents from the action of re-agents. Diluted nitric acid is generally used in these trials.

To the characters taken from certain physical properties, are referred the Phosphorescence, Electricity, and Magnetism of minerals. Phosphorescence is peculiar to some minerals, and is therefore a property well adapted to assist in their discrimination. In some it is excited by attrition more or less strong, in others by exposing them to heat. The electrical state, either positive or negative, is excited in some minerals by rubbing, in others by heat, and iron in many states of combination is discovered by its magnetic power.

Lastly, advantage is sometimes taken in the discrimination of minerals, of what are named Empirical Characters; of which, perhaps, the most important is that derived from the natural association of minerals: some being very frequently found in the same situation, and even blended with each other; while there are others which have never been observed to occur together.

CHAP. I.

OF SALINE MINERALS.

IN mineralogical systems, the term Fossil Salts has been appropriated to those native compounds of acids with certain bases, which are sapid, have a very evident solubility in water, and are crystallizable. The order includes, therefore, not only the native salts having these characters, which are formed from the union of an acid with an alkali, but also several, of which an earth or metal is the base, while it excludes a number of compounds of acids with earths, and with metals, which having no evident solubility, or saline character, are placed among the earthy or metallic fossils. In conformity to chemical arrangement, I use the term in a more limited sense, applying it to those native salts which are formed by the union of acids with alkalis; the others being placed under the earths or metals to which they belong. Agreeable to the same principles of arrangement, these substances are arranged as genera according to the base of which they are formed.

SECT. I.

OF NATIVE SALTS WITH BASE OF AMMONIA.

UNDER this genus can be placed only one species, MURIATE OF AMMONIA, or NATURAL SAL AMMONIAC, and even its claim to be ranked as a mineral production is somewhat doubtful. It is always the product of volcanoes, or pseudo-volcanoes, being probably formed by the action of heat on substances containing its elements, and sublimed. It occurs as an efflorescence, loose and flaky, and sometimes also massive, tuberoso, botryoidal, and crystallized, the crystals being very minute. It is of a greyish or yellowish white colour, its taste is acrid, it is abundantly soluble in water, and is easily distinguished by its chemical characters, being volatilized when heated, and exhaling a strong smell of ammonia when rubbed with lime. A small portion of sulphate of ammonia is mixed with it. A variety of the natural sal-ammoniac of Bucharja, consists, according to Klaproth's analysis, of muriate of ammonia 97.5, sulphate of ammonia 2.5. A variety from Vesuvius consisted entirely of muriate of ammonia with $\frac{1}{2}$ per cent. only of muriate of soda.

SECT. II.

OF NATIVE SALTS WITH BASE OF POTASSA.

To this genus there belongs also only one species, NITRE or NATIVE SALTPETRE, and it too can scarcely be regarded as a mineral production, since it is formed only at the surface of the earth, and by operations which depend on the action of atmospheric air. It occurs as an efflorescence on the soil in many warm and dry climates, particularly in India, and also in Spain and Hungary, being formed probably from the slow decomposition of the vegetable and animal matter with which the soil is impregnated, nearly in the same manner as in artificial nitre beds. It is also found efflorescing in certain situations on limestone rocks, or in limestone caves; and in such situations is probably formed, as has been already explained, by the action of carbonate of lime on the oxygen and nitrogen of the atmosphere promoting their combination so as to form nitric acid, and the limestone perhaps affording the potassa with which this combines. There is accordingly a constant reproduction of it. This is the case at the celebrated Nitre Pit at Molfetta in Apulia. It is there intermixed with sulphate of lime, and with the limestone to which it adheres; and Klaproth found there is also associated with it a small quantity of an alkaline muriate, which he supposed to be muriate of potassa. It forms thin layers, of a crystalline appearance, and of a greyish or yellowish white colour; and is easily distinguished

by its cool taste, and its chemical characters, particularly that of detonating on burning fuel.

SECT. III.

OF NATIVE SALTS WITH BASE OF SODA.

UNDER this genus, four salts are comprised, sulphate of soda, carbonate of soda, muriate of soda, and borate of soda.

SULPHATE OF SODA.—This salt is a very common ingredient in saline mineral springs, and is sometimes found on the borders of salt lakes, probably deposited in consequence of the evaporation of the saline water. It is also sometimes found as an efflorescence on the soil, particularly in the neighbourhood of salt lakes; hence too, it is often mixed with muriate, and sometimes with carbonate of soda. It occurs loose, in layers, sometimes stalactitic, or crystallized; has the general characters of the salt itself, and is easily discerned by chemical tests, particularly by not effervescing with acids, giving a precipitate with muriate of barytes, and not being precipitated by carbonate of soda.

CARBONATE OF SODA is found native in considerable quantity in different countries, and under different forms. In some districts in Syria and India, and even in some countries in Europe, it occurs in the form of an efflorescence on the soil in certain situations. In some of the interior parts of Africa, particularly in the kingdom of Tripoli, it is found in crystalline encrustations or layers,

of the thickness of from one-third to half an inch, exhibiting a striated fracture, being apparently composed of acicular crystals, which are aggregated. This forms what has been named Trona. It was analysed by Klaproth, and when freed from the sand adhering to it, was found to consist of 37 of soda, 38 of carbonic acid, 22.5 of water of crystallization, and 2.5 of sulphate of soda. The soda in this native production is therefore combined with a much larger quantity of carbonic acid than exists in the artificial carbonate. Another variety of native carbonate of soda is found adhering to the bottom and sides of certain lakes, which becoming dry during the summer-season, admit of it being extracted. In Hungary, there are lakes of this kind, and in Egypt it has been produced in this way from the most remote period, and has lately again become an object of commerce. In the French expedition to that country, an opportunity was afforded of examining the Natron Lakes, as they have been termed. They are situated, six in number, in a valley, about twenty leagues north-east from Cairo. The valley is surrounded with calcareous rocks; the bottom of the lakes is chalk mixed with sand, and the soil is impregnated with common salt. The water found in the lakes contains muriate of soda, carbonate of soda, and a small quantity of sulphate of soda; the borders of the lakes are covered with crystalline masses, and the sides and bottom are encrusted with saline matter. These masses are of a granular crystallized structure, of a greyish-white or light brown colour. The natron differs considerably in its purity, some of it being nearly pure carbonate of soda, and other specimens containing a large proportion of muriate

of soda and sulphate of soda, mixed with carbonate of lime, and sand. Berthollet ascribes its formation, with much probability, to the infiltration of water through the soil, which dissolves the muriate and sulphate of soda, and presents it to the extensive surface of carbonate of lime, the action of which is aided by the efflorescence from the porosity of the soil, and the reeds which grow in it; whence the carbonate of soda, as it is formed, is abstracted from the action of the muriate of lime*. It might be supposed, that all the varieties of this saline fossil have some such origin. The trona of Africa, however, must be excepted, as it has no contamination of muriate of soda.

MURIATE OF SODA.—This is the most important of the native salts, and the one which can be most truly regarded as a mineral production, since it is found not merely at the surface, but in immense quantity in the interior parts of the earth. Rock Salt, as it is named in mineralogical nomenclature, is in large masses, having always a crystalline structure, and sometimes a crystalline form, its crystals being cubes. It is of a white, grey or reddish colour, sometimes, though more rarely, blue, yellow, or deep-red; it is translucent; sometimes semi-transparent, or transparent, having considerable lustre, inclining to vitreous. Its fracture is foliated with a threefold rectangular cleavage, and its fragments are cubical; one variety has a fibrous fracture. It is easily broken; has a specific gravity of 2.14. Its taste is purely saline. In general, it is pure muriate of soda, or contains no foreign

* *Mémoires relative to Egypt*, p. 253: 324.

salts. Its colours have been supposed to depend on oxide or muriate of iron. As a mineral production, rock salt is very extensively distributed. It is generally in beds, short, and very thick, connected with rocks of secondary formation, and more particularly associated with a species of indurated clay, gypsum, lime-stone, and sand-stone. There are immense deposits of it, as in the east and south of Germany, where it is found over a very extensive tract. In Spain it is abundant, and in some districts rises even to the height of 500 feet above the surface. There is another large deposit of it in Cheshire. In the other divisions of the globe, it is not less extensively distributed. Salt springs, which are found in so many countries, probably always arise from the infiltration of water over beds of rock salt, or rocks in which it is disseminated.

SUB-BORATE OF SODA.—The salt from which the Borax of commerce is procured, and which consists of boracic acid combined with soda, the soda being in excess, is a native production, being obtained from a lake in Thibet. It is in masses, or disseminated, but more generally crystallized, its crystals being hexaedral prisms, often of considerable size. The surface of the crystals in the state in which they are imported, is usually greasy, from an artificial process, it is said, to which they are subjected to prevent their efflorescence. When broken, the colour is greenish or yellowish white, with a semi-transparency, and a vitreous lustre: the fracture is foliated. Its taste is mild; it is soluble in water, and it melts with intumescence before the blowpipe. There is some obscurity with regard to the origin of borax. According to the account given by Mr Saunders, who visited Thibet, the native

Borax, or Tincal, as it is named, is deposited or formed in the bed of the lake ; it is dug in large masses ; and although this has been done for a long period, the quantity is not perceptibly diminished, the cavities made by digging it being soon filled up. It is principally dug from the sides and shallower places, while from the deeper parts rock salt is said to be brought up. The lake, which is of 20 miles circumference, is supplied by no stream, but by springs from the bottom *.

CHAP. II.

OF EARTHY MINERALS.

UNDER this order are comprised the fossils formed by the combinations of the earths with each other, or with certain acids. The fixed alkalis enter into the composition of some of these compounds, as do also several of the metallic oxides in smaller proportion. The order is subdivided into genera ; each earth, according to the principles of chemical arrangement, forming a genus, to which are referred those fossils, of which it is the principal ingredient, or to which it gives the predominating characters ; allowance being made, in these arrangements, for the present imperfections of chemical analysis ; and due attention being therefore paid to analogies in properties, so as to establish as nearly as pos-

* Philosophical Transactions, vol. lxxix. p. 97.

sible a natural system. It is obvious, that in a system of chemistry, those species only can be admitted which are clearly established, leaving for future determination, such as from recent discovery, or imperfect examination, are more doubtful or obscure, and which may be only varieties of species already received.

To this order of minerals, no common characters can be assigned with any precision. They are connected entirely by chemical relations. They have been in general said, however, to be light, or only moderately heavy; of pale colours, destitute of metallic lustre, unflammable, insipid, and insoluble.

SECT. I.

OF BARYTIC MINERALS.

UNDER this genus there are only two proper species, the Sulphate, and the Carbonate. They are distinguished from other earthy fossils, by their greater specific gravity.

SULPHATE OF BARYTES.—The Heavy Spar of mineralogists forms several sub-species, principally from its state of aggregation or texture. The common variety, the Straight Lamellar, as it has been named from its fracture, occurs massive, and often crystallized: the forms of its crystals are numerous, but they are all reduced to the oblique four-sided prism, and the rectangular four-sided table; each being either perfect, or modified by truncation or bevelling of the edges or angles. The colour of this fossil is white, frequently with shades of

grey, yellow, brown, or red : its internal lustre is shining, and intermediate between pearly and vitreous : it is transparent, semi-transparent, and, when massive, often only translucent : its fracture is straight foliated, with a threefold cleavage ; and its fragments approach to the rhomboidal form. Its hardness is intermediate between that of calcareous and fluor spar : it is brittle and heavy, its specific gravity being from 4.3 to 4.5. It melts before the blowpipe into a white enamel, which, when moistened, gives an odour of sulphuretted hydrogen ; proving that the sulphate has been partially decomposed by the carbonaceous matter of the flame. The discordant results with regard to its composition have been already stated, under the history of the artificial sulphate. Klaproth found, in several varieties of it, small proportions of sulphate of strontites, silex, argil, and iron.

The other varieties of native sulphate of barytes, are in a chemical, and some of them even in a mineralogical point of view, so unimportant, as scarcely to require distinct notice. One variety has, instead of a straight foliated, a curved foliated fracture, which even passes into splintery, occurs generally massive, sometimes crystallized in four-sided tables or lenses. Another, named Granular Heavy Spar, presents a fracture very small, and fine foliated ; this variety is composed, according to Klaproth, of 60 of barytes, 30 of sulphuric acid, and 10 of silex. The Compact Heavy Spar has a fracture fine grained uneven, passing into coarse earthy ; has less lustre than the preceding varieties ; is opaque, or only translucent on the edges, and is always massive ; and sometimes the induration is so inconsiderable, as to form an

earthy variety, which is dull, and feels rough and meagre. Columnar Heavy Spar derives its name from the appearance of its crystallized masses, which are composed of oblique four-sided prisms, aggregated in a columnar form: it has a perfectly pearly lustre; is translucent; and its fracture is straight foliated. What has been named the Bolognian Heavy Spar, occurs in rounded masses, and presents a radiated fracture: the rays, or narrow planes, being parallel or divergent: it is translucent; and its internal lustre is shining and resinous. The chemical characters of all these appear to be the same.

CARBONATE OF BARYTES.—This fossil occurs in veins massive, also in globular pieces, and rarely crystallized. Its crystals are six-sided prisms acuminate by six planes, and double six-sided pyramids: its colour is white, with a shade of yellowish-grey: it is translucent, or semi-transparent; and its lustre is shining, and approaching to resinous. Its fracture, in one direction, is intermediate between radiated and foliated, approaching generally more to the former: in another it is uneven: its fragments are wedge-shaped: it is semi-hard: it is rather less heavy than the native sulphate, its specific gravity being 4.3. It is fused by the flame of the blowpipe into a white enamel: it dissolves with effervescence in diluted nitric acid. According to Withering, it consists of barytes 78.6, carbonic acid 20.8. Pelletier makes the proportions, barytes 62, carbonic acid 32, water 16; Klaproth, barytes 78, and carbonic acid 32; and Vauquelin, barytes 74.5, carbonic acid 25.5. Klaproth also found in it a small quantity of carbonate of strontites, about 1.7 in 100 parts, with minute traces of argil, oxide

of copper, and oxide of iron. It is found principally at Anglesark in Lancashire, and in Cumberland.

SECT. II.

OF STRONTITIC FOSSILS.

THE natural species of this Genus are those in which the earth is mineralized by sulphuric and by carbonic acids. The SULPHATE has been discovered subsequent to the discovery of the native carbonate, and appears to be more widely diffused, being found in some of the western countries of England, in France, Sicily, and Pennsylvania. It occurs massive, and crystallized in six-sided tables, or in rhomboidal four-sided prisms acuminated by four planes. Its colour is milk-white, frequently with a shade of blue, which deepens into sky-blue, and, in one variety, is of a grey colour, or sometimes of a reddish tinge. The crystals are semi-transparent, or translucent: the massive nearly opaque: its lustre, when crystallized, is more or less shining: when massive, it is dull. The fracture is foliated, fibrous, or compact fine splintery. The different varieties, which are distinguished principally by fracture, are semi-hard, sometimes approaching to soft: their specific gravity is from 3.5 to 3.8. Mr Clayfield's analysis gave as the constituent parts of this fossil, strontites 58.25, sulphuric acid 41.75, with a little oxide of iron; with which Klaproth's exactly agrees. Vauquelin has in some varieties found 8 or 10 parts of carbonate of lime. From its sky-blue colour, it has received the name of Cœlestine.

The CARBONATE has hitherto been found only at Stron-

tion in Argyleshire. It is usually massive : sometimes from the mass, or in cavities of it, slender crystals shoot, which, when their form can be determined, appear to be six-sided prisms acuminated by six planes. Its usual colour is light green : frequently it is only of a greenish-white, sometimes of a yellowish colour ; its lustre is more or less shining, and is pearly : its fracture is fibrous, or radiated ; the fibres being straight, and generally diverging : it is semi-hard, brittle ; has a specific gravity of 3.6 or 3.7. Before the flame of the blowpipe, it becomes white and opaque, but is not fused. With soda or borax it melts into a vitreous enamel. It dissolves in diluted nitric acid with effervescence. According to Dr Hope's analysis of it, it consists of strontites 61.21, carbonic acid 30.2, water 8.59. With this Pelletier's almost exactly corresponds ; the proportions he assigns being strontites 62, carbonic acid 30, water 8. Klaproth states them at 69.5 of the earth, 30 of the acid, and only 0.5 of water.

SECT. III.

OF CALCAREOUS FOSSILS.

THE fossils which belong to the calcareous genus all consist of lime, in combination with different acids. Hence, as there is no ambiguity in their composition, their arrangement on chemical principles can be established with perfect precision.

SULPHATE OF LIME may be placed as the first species. Mineralogists have generally given it the name of Gyp-

sum, and, when crystallized, Selenite. Four varieties of the species have been formed, from a difference in aggregation or texture,—the Earthy, Compact, Fibrous, and Foliated. The Selenite may be arranged with the last, though Werner has chosen to make it a distinct species.

The Earthy Gypsum receives its name from its state of induration, being pulverulent, or slightly indurated; of a yellowish or greyish-white colour; dull, and meagre to the touch: it appears to originate entirely in the disintegration of the other varieties, and does not often occur.

Compact Gypsum is the substance which is properly named Alabaster, and which is used for statuary. It is always massive: its fracture is even; sometimes scaly: its colours are usually shades of grey, and are often intermixed: it has little lustre, though it acquires it when its surface is polished: it is translucent on the edges, and very soft: its specific gravity is from 1.8 to 2.2.

Fibrous Gypsum is the variety which, next to the foliated, is most common. It occurs massive: its fracture is distinctly fibrous, more or less broad; the fibres being straight or curved, and always parallel: its usual colour is white, frequently with shades of grey, yellow, or red; sometimes it is of a deeper yellow or red: its lustre is shining and silky: it is translucent, or semi-transparent; is so soft as to be scratched by the nail: its specific gravity is 2.3.

The last variety, the Foliated Gypsum, including the Selenite, occurs both massive and crystallized; the forms of its crystals being the oblique six-sided prism bevelled, or acuminate by four planes at each extremity. These crystals are often united, so as to form a twin crystal;

the prism sometimes terminates in spherical convex planes ; sometimes the prism is even wanting, and these planes united form a spherical convex lens. The colours of the varieties of foliated gypsum are generally white, with frequently the shades which the other varieties also present : its lustre, when crystallized, is shining and highly shining, generally pearly : when massive, it varies from shining to weakly shining : it is also, when crystallized, transparent ; when amorphous, it varies from this to translucent : its fracture is curved foliated, with a single cleavage ; sometimes diverging radiated : that of what has been named Selenite is large and perfect foliated, generally straight, though sometimes curved, with a three-fold cleavage, one of which only is well determined : it is easily split : the fragments are indeterminate, with blunt edges, or, in the selenite, rhomboidal : it is soft, so as to be scratched by the nail ; feels smooth ; has a specific gravity of 2.3.

All the varieties of native sulphate of lime have nearly the same chemical characters. Heated before the flame of the blowpipe, they lose the transparency they have, and become white : when strongly urged by the flame, they give a white or yellowish enamel ; the gypsum being partially decomposed. When pure, they do not effervesce with acids, though there is sometimes a slight effervescence from intermixture of carbonate of lime : they are soluble in sulphuric acid, when its action is aided by heat. The proportions of their constituent principles perhaps vary a little, especially of the substances which do not appear to be essential to the composition. According to Bergman, selenite consists of lime 32, sulphuric acid 46,

water 22 : the several varieties frequently also contain carbonate of lime, oxide of iron, argil, and silex. This fossil is found in extensive strata, sometimes in veins.

A native sulphate of lime has been discovered, into the composition of which water does not appear to enter, and which perhaps forms therefore a distinct species. It has been named the Anhydrous Gypsum. It appears to occur massive, as well as crystallized ; the usual forms of the crystals, as described by Bournon *, being a rectangular four-sided prism, having two opposite planes broader than the others, and sometimes truncated on the lateral edges, so as to form a prism of eight sides : their external lustre is shining and pearly : they are more or less transparent ; their colours white, grey, bluish, or flesh-red. The hardness of this fossil is much greater than that of the common gypsum, exceeding even that of carbonate of lime ; its fracture is imperfect and curyed foliated : its specific gravity, when it is pure, is 2.9. It is phosphorescent when heated, and is fusible by the blowpipe, without ebullition, into an opaque glass. According to Mr Chenevix's analysis of it, it consists of 44.88 of acid, and 55.12 of lime †. The common sulphate calcined, he states as the same composition. The Anhydrite, and the Cube Spar of Werner, have both been described as anhydrous sulphate of lime.

CARBONATE OF LIME.—This fossil occurs in very different states, arising both from differences in its aggregation, and from the intermixture of other substances besides its immediate constituent principles. There is hence consi-

* Nicholson's Journal, 8vo, vol. ii. p. 190.

† Ibid. 8vo, vol. ii. p. 196.

derable difficulty in arranging its varieties, and in determining whether some of them ought not even to be regarded as distinct species.

CRYSTALLIZED CARBONATE OF LIME, or what has been named Calcareous Spar, is the species in its purest state, or consisting only of lime and carbonic acid, with a portion of water. When it occurs amorphous, or of irregular forms, it still presents the crystalline structure; but it more generally occurs regularly crystallized. The primary forms of its crystals are the six-sided pyramid, the three-sided pyramid, and the six-sided prism; but these undergo numerous modifications from combination, acumination, bevellment, and truncation, giving rise to a variety of other forms: its crystals are often aggregated: they are generally transparent, or semi-transparent: in its amorphous state, it varies from transparent to translucent: it has very distinctly, when sufficiently transparent, the property of double refraction, and is the first fossil indeed in which this was observed: the external lustre of the crystals is usually shining and resplendent: the internal lustre varies from resplendent to weakly shining, and is commonly vitreous, sometimes pearly: the usual colour is white, but other colours also occur, as grey, green, red, yellow, and light purple. The fracture of calcareous spar, in all its forms, is perfectly foliated, with a threefold cleavage: its fragments are always rhomboidal: it is semi-hard, so as to be very easily scratched by the knife: it is also brittle: its specific gravity is 2.7. It decrepitates before the flame of the blow-pipe, but is perfectly infusible. Some varieties of it are phosphorescent when laid on burning fuel: by a full red

heat it is decomposed, its carbonic acid being expelled : it effervesces strongly with the acids, and is entirely soluble in diluted nitric or muriatic acid. According to its analysis by Bergman, it consists of lime 55, carbonic acid 34, water 11. From Vauquelin's analysis, it appears to contain less water, and indeed scarcely any appreciable quantity ; the constituent principles of a very pure rhomboidal fragment of calcareous spar, being lime 56, carbonic acid 43.5. With this an analysis by Mr Aikin agrees ; the proportions being carbonic acid 44, lime 55.475, and water .525 *.

There are some crystallized fossils, which, from the most accurate chemical analysis, can be discovered to consist only of carbonate of lime, yet which differ from the common calcareous spar in some of the most essential characters. What has been named Arragon Spar, or Arragonite, is the fossil with regard to which this was first observed. Haiüy, in subjecting it to crystallographical examination, found that the cleavage was different from that of calcareous spar, indicating a different crystalline arrangement, and a difference in the forms of their primitive molecules ; they differ also in other external characters, particularly in hardness and specific gravity. It occurs crystallized in hexaedral prisms, either perfect, or bevelled at the extremities : its colour is grey : its lustre shining and vitreous : it varies from transparent to translucent, and gives a double image : its fracture is imperfectly foliated : it is much harder than common calcareous spar, so as to scratch it easily : its specific gravity

* Philosophical Magazine, vol. xiv. p. 290.

is also greater, being 2.946. It effervesces with acids, decrepitates and calcines without fusion. The essential difference in some characters, especially in the crystalline structure, between this and common calcareous spar, has repeatedly led to its analysis, but it has been found only composed of lime and carbonic acid, without any trace of foreign ingredient. This was the result of the analysis executed by Klaproth. The investigation was also undertaken by Thenard, and every means employed to discover any other principles; but the result still was, that the arragonite is a pure carbonate of lime, and that the proportion even between the acid and the base, is the same as in the crystallized calcareous spar. And still more lately, when the inquiry was resumed by Fourcroy and Vauquelin, the perfect identity of the two fossils, with regard to the quantity of lime, of carbonic acid, and of water which they afforded, was established, or with differences so trivial as to be perfectly inadequate to explain the difference in characters. 100 parts of arragonite afforded, by solution in nitric acid, 43 of carbonic acid gas, and, by calcination, 55 of lime; the same quantity of pure calcareous spar from Iceland gave, by solution, 43.5 of gas, and, by calcination, 56 of lime*. This fossil still continues, therefore, to afford the greatest difficulty in the crystallographic system of Haüy, and presents undoubtedly a singular anomaly.

The hard carbonate of lime described by Bournon †, and which exhibits a similar anomaly, is probably to be placed with the arragonite. Its specific gravity is nearly

* *Annales de Museum National.* tom. iv. p. 405.

† *Philosophical Transactions*, 1803, p. 325.

the same, being 2.912: its hardness is equally superior to that of calcareous spar, but it also exceeds a little that of the arragonite itself: there appears to be some difference in its crystalline structure; and the arragonite is more highly phosphorescent; these are differences, however, not sufficiently important to establish them as distinct species. Mr Chenevix, in analysing it, was equally unable to discover any difference in composition between it and common carbonate of lime.

FIBROUS CARBONATE OF LIME.—This variety, distinguished by its fibrous texture, occurs always massive, or in various imitative shapes; the stalactites and stalagmites, which are deposited from water, holding carbonate of lime in solution, belong to it, but it also occurs, not of stalactitic origin, in veins. This latter variety is in its fracture distinctly fibrous; the fibres being straight and parallel; its colour is white, with often a shade of grey, yellow, or red; its lustre is more or less shining, and is pearly; it is more or less translucent; is semi-hard, and gives splintery fragments. Its chemical characters are the same with those of calcareous spar, and its composition appears to be similar. The satin spar of Cumberland, which is a fibrous carbonate, analysed by Mr Pepys, gave of lime 50.08, carbonic acid 47.6, there being a loss of nearly three parts, consisting probably of water*.

The stalactitic carbonate of lime, the other variety of the fibrous kind, is, from the nature of its formation, presented under various external shapes, conical, tuberosc, coralliform, and botryoidal. Its colour is usually white,

* Philosophical Magazine, vol. xii. p. 367.

but frequently with shades of grey, yellow, red, and green, more or less deep: its lustre is usually weakly shining; it is translucent, approaching to semi-transparent; its fracture is fibrous; the fibres being straight, and generally divergent; it is rather softer than the calcareous spar: its specific gravity is 2.7. Its chemical characters are the same with those of the other varieties of carbonate of lime. Bergman states its composition at 64 of lime, 34 of carbonic acid, and 2 of water. The Pisolithe, or Peastone, so named from the mass being composed of small rounded concretions like peas, which consist of carbonate of lime, often with a grain of sand in the centre of each, appears to be of similar origin. Roestone is probably connected with this. It is in mass composed of small globular concretions, dull, opaque, of a brown or yellowish colour, soft, and easily broken.

GRANULAR CARBONATE OF LIME, or GRANULAR LIMESTONE.—This always occurs massive, forming very extensive strata, generally connected with the primitive rocks, or those of transition; and hence sometimes receiving the name of Primitive Limestone. In its structure, it shews indications of a crystalline arrangement; its fracture is small foliated, sometimes splintery, and presents granular distinct concretions, often so small and fine, that the foliated texture is discerned with difficulty; its usual colours are white and grey, with sometimes shades of yellow, green, red, or blue, these colours being seldom intermixed; its lustre varies from shining to glimmering, and is intermediate between pearly and vitreous; it is more or less translucent; it is semi-hard, rather harder than calcareous spar, and less brittle. Its specific gravi-

ty is 2.7 or 2.8. It effervesces with acids. To this belongs the fossil which has been named Dolomite. It is a granular limestone, yet it has some qualities different from the common: its granular concretions are smaller, so that the foliated fracture can scarcely be perceived: it has less transparency and lustre: it is usually phosphorescent, and it effervesces less with acids, and is more slowly dissolved.

The analysis of granular limestone has been extended to few of its varieties. It appears often to be a carbonate of lime nearly pure, but it sometimes also contains silex, argil, and magnesia, in proportions variable, and not well determined. In Carrara marble, which is one of the purest of this family, Kirwan found only 0.03 of argil, with 45 of carbonic acid. The variety named Dolomite, analysed by the younger Saussure, gave lime 44.29, argil 5.86, magnesia 1.4, carbonic acid 46.1, and iron 0.74. Mr Tennant, finding that some varieties of limestone, which contained a considerable proportion of magnesia, were very slowly dissolved by acids, though the state of aggregation was by no means such as to oppose any obstacle to the solution, supposed that was owing to the presence of magnesia*; and hence that in the dolomite, the same property is to be ascribed to the same cause. But Bournon has remarked, that there are carbonates of lime highly charged with magnesia, that are quickly dissolved by acids; and he supposes the peculiar characters of the dolomite, compared with the other limestones, may arise from the absence of water in its composition†.

* Philosophical Transactions, 1799, p. 309.

† Nicholson's Journal, 8vo, vol. ii. p. 195.

The granular limestone furnishes some of the finest marbles, and particularly those which are used for statuary.

COMPACT CARBONATE OF LIME, or Compact Limestone.—In this fossil, the common limestone, the carbonate of lime is much less pure: other substances are generally present even in considerable proportion, and hence it wants the characters which belong to the purer varieties. Its fracture is always compact, generally small scaly, passing into large conchoidal, uneven or earthy. Its usual colour is grey, but frequently diversified with shades of other colours: it is dull, and a little translucent on the edges: it is semi-hard, passing to soft; has a specific gravity of 2.6 or 2.7. It occurs always massive, generally regularly stratified, and in connection with other secondary strata: it often contains in great abundance the remains and impressions of organic beings, particularly of marine animals. Its composition varies considerably: the base is always carbonate of lime, but with this are intermixed, in the several varieties, variable and often considerable proportions of argil, silex, magnesia, and oxide of iron. In burning into lime, they lose from 25 to 35 of their weight. Those of them which are of a very compact texture and fine grain, are often polished as marbles.

Chalk is a carbonate of lime nearly pure, and which appears to derive its external characters principally from its state of aggregation. It occurs massive, generally in beds; is little indurated: its fracture is earthy: its colour white, or yellowish, dull, and opaque; is so soft as to soil; its specific gravity is 2.3. It dissolves readily in acids with considerable effervescence.

Marl appears to stand in the same relation to compact

limestone, that chalk does to the purer varieties of carbonate of lime, being an impure carbonate in a loose state of aggregation. There are two varieties of it,—the earthy and indurated; the former is composed of earthy particles, little cohering so as to soil; is dull, and feels somewhat meagre: the other is more indurated, but is still so soft as to yield to the nail; has an earthy fracture; is usually of a grey colour; is quite dull and opaque; effervesces with acids, and generally falls to powder in water, or even under exposure to atmospheric air. Marls contain, besides carbonate of lime, generally clay in largest proportion, and, next to this, magnesia, siliceous, and oxide of iron, in very variable quantities. The medium proportion of carbonate of lime is from 50 to 60 *per cent.*

The Bituminous Marl Slate is more highly indurated, and has a slaty fracture. It occurs stratified, and is distinguished by frequently having impressions of fish.

There remain some fossils, in which carbonate of lime is chemically combined with other principles, and which perhaps properly constitute distinct species.

Pearl spar is a fossil of this kind; being composed of carbonate of lime, with oxides of iron and manganese, forming a series in which these are present in variable quantities, and in which, when they become abundant, there is the transition into what is named Sparry Iron Ore. Pearl Spar, or, as it has also been named, Brown Spar, or Sidero-calcite, occurs massive, disseminated, and crystallized; its crystals being rhombs, or lenses: its colours are white, often with shades of grey, yellow, or red; but, from exposure to the air, its colour darkens, it becomes brown, and at length nearly black. Its lustre is

shining and pearly : it is semi-transparent ; when massive, only translucent : its fracture is foliated, (one variety of it has a fibrous fracture) ; the lamellæ are more or less curved : it has a triple cleavage : its fragments are rhomboidal : its hardness is a little greater than that of calcareous spar : its specific gravity is also rather greater, being 2.8. It does not melt before the blowpipe ; but instead of becoming white like calcareous spar, it blackens : it effervesces with acids, but not strongly. According to Bergman's analysis of it, it consists of 50 parts of carbonate of lime, 22 of oxide of iron, and 28 of oxide of manganese ; but, from its transitions from calcareous spar into sparry iron ore, it is probable, that the proportions of the metallic oxides in its composition are various. The oxide of manganese appears to be at the minimum of oxidizement ; and it is from it gradually absorbing oxygen, that the change of colour which pearl spar suffers from exposure to the atmosphere happens.

What has been named Rhomb Spar, Bitter Spar, or Muria-calcite, consists of carbonate of lime, with carbonate of magnesia, and a little oxide of iron and oxide of manganese ; the first, in one specimen analysed by Klaproth, amounting to 52 parts, in another to 73 ; the second, in the one to 45, in the other to 25 ; and the oxides of iron and manganese to 3 or 2.25. It occurs crystallized in rhombs, which are semi-transparent, or translucent ; has a shining lustre, intermediate between vitreous and pearly, and is of a white or grey colour. Its fracture is straight foliated, with a threefold cleavage : its fragments are rhomboidal : it is rather harder than calcareous spar : its specific gravity is less, being only 2.48. It is

not fused before the blowpipe, but becomes brown. It effervesces little with acids, and only when it is in powder.

The Schieffer Spar, or Argentine, has some relation to these fossils in certain external characters. It occurs always massive; has a high pearly lustre; is translucent, and of a white colour, with shades of green or red: its fracture is curved foliated, approaching to slaty, with a single cleavage: its fragments are slaty, or wedge-shaped; is soft, so as to be scratched by the nail: its specific gravity is 2.7. It effervesces strongly with acids, even more so, it is said, than calcareous spar itself. Heated to redness, it becomes brown, and may be fused, by raising the heat, into a brown porcelain. Its composition was but imperfectly known, further than that it consisted principally of carbonate of lime. It has been analysed, however, by Mr Aikin, who has stated its composition at—carbonate of lime 98.118, siliceous 0.5, oxide of iron .8, with 1.032 of loss*: It is difficult to conceive that these small portions of foreign substances should give rise to the characters that it presents, different from those of carbonate of lime. This fossil appears to pass into what has been named Silvery Chalk, or Schaum Earth; which has the same pearly lustre and colours, and a fracture curved foliated, but occurs in a less state of induration, being so soft as to soil, and sometimes being composed of fine scaly particles nearly loose. Nor does what has been named Schaalstone appear to be very essentially different: like the preceding, it occurs massive; is of a white colour, with shades of green, red, or yellow, and a lustre

* Philosophical Magazine, vol. xiv. p. 292.

shining and pearly. Its fracture, too, is foliated, with a single cleavage : it is translucent and semi-hard. It has been supposed to consist of carbonate of lime, with siliceous matter.

The last variety of carbonate of lime is the Foetid Carbonate, or Swinestone, which, according to Vauquelin, is a carbonate of lime impregnated with sulphuretted hydrogen, from which it derives an unpleasant odour, especially perceptible when rubbed. It occurs massive in beds: its colour is brown, with little lustre ; is opaque : its fracture is earthy, or scaly, inclining often to slaty. When heated, it loses its colour and smell, and is converted into lime.

PHOSPHATE OF LIME.—This species occurs under very different forms, which can be connected only by their chemical characters.

In the province of Estramadura in Spain, it is found massive in extensive strata, forming with quartz an entire mountain, forming the mineral which has received the name of Phosphorite. It is in an earthy or little indurated state. Its colour is yellowish or greyish white, without lustre or transparency ; rough to the touch ; and having a specific gravity of 2.8. It is distinguished by a high degree of phosphorescence when heated, or even when merely rubbed : when thrown on burning fuel, it gives a beautiful yellow light. This substance was analysed by Pelletier, who found it to consist of lime 59, phosphoric acid 34, fluoric acid 2.5, siliceous matter 2, iron 1, with a trace of carbonic and muriatic acids.

The fossil which has received the name of Apatite is another variety of phosphate of lime. It occurs generally crystallized ; the form of its crystals being the equiangular six-sided prism, sometimes so low as to form the six-

sided table, and often truncated on the lateral edges and angles, or on the terminal edges: the crystals are generally small and grouped: their colours are white, green, blue, and red of various shades, generally pale; their external lustre resplendent; the internal lustre shining, and intermediate between resinous and vitreous: they vary from transparent to translucid: the fracture is imperfectly foliated, the cross fracture uneven: its hardness is such, that it is easily scratched by the knife, and is inferior to that of fluat of lime: its specific gravity is 3.2. When thrown on burning fuel, it gives a greenish phosphoric light. It loses its colour, but does not melt before the blowpipe. It is soluble in nitric acid. According to Klaproth's analysis of it, it consists of 55 of lime and 45 of phosphoric acid.

There is still a third variety of phosphate of lime, different in its external characters from either of the preceding. It is one of several fossils which, from their agreement in lustre, transparency, and in a greenish-yellow colour, had been confounded under the name of Chrysolite; and it possesses these qualities in so high a degree, as to have been ranked as a gem. On analysing it, Vauquelin was surprised to find it composed of phosphoric acid and lime; and Haiiy, on comparing its characters, drawn from the primitive form of its crystals, with the preceding variety, the apatite, found that they were precisely the same. This fossil occurs crystallized; its crystals being equiangular six-sided prisms, acuminated by six planes, with the lateral edges sometimes truncated. Its colour is asparagus-green, whence it has received the name of Asparagus or Spargel Stone: it passes, however, into

other shades of green : its lustre is shining or resplendent, and resinous : it varies from translucent to nearly transparent : its fracture is foliated : it is semi-hard ; brittle ; and has a specific gravity of 3. It is soluble in nitric acid, and in diluted muriatic acid, without effervescence ; but does not, like the other varieties of this species, give any phosphoric light on burning fuel. It is not melted by the blowpipe. The proportions of its constituent parts were found by Vauquelin to be 53.32 of lime, and 45.72 of phosphoric acid ; which agree almost precisely with the proportions of the apatite as assigned by Klaproth.

FLUATE OF LIME.—This fossil, distinguished very generally by the beauty of its colours, occurs under two varieties with regard to texture,—the compact and the foliated ; the latter of which is by far the most common, and is the mineral to which the name of Flour Spar is generally given. It is found massive, and frequently also crystallized : the forms of its crystals are the cube, perfect, or modified by truncation of the angles, truncation of the edges, bevelling of the edges, and acumination of the angles by three or by six planes. Its colours are extremely diversified, principally shades of purple, yellow, green, blue, red, and grey, and often intermixed : the lustre is resplendent or shining, and is vitreous : the transparency varies from perfectly transparent to translucent : the fracture is more or less perfectly foliated, with a four-fold cleavage : its fragments are tetraedral, octaedral, or rhomboidal : its hardness is such that it is scratched by the knife, but it scratches calcareous spar : it is brittle : its specific gravity is 3.1 or 3.2. When exposed to the flame of the blowpipe, it first decrepitates, and then

melts into an enamel of a greyish-white colour. When placed on burning fuel, or on a red hot iron, it gives a beautiful purple light, and is also phosphorescent from friction. We are indebted to Scheele for the analysis of this fossil, as well as the discovery of the acid it contains. Its composition, as established by his experiments, is lime 57, fluoric acid 16, water, 27.

The variety which is named Compact Fluor, is distinguished principally by its fracture, which is even, approaching sometimes to imperfect conchoidal, or to splintery: it is always massive, generally of a greenish or greyish-white colour; has much less lustre than the foliated; and is only translucent. It is much more rare.

Fluor Spar is found almost always in veins, and generally accompanying some metallic ores, particularly those of lead and tin. In England it abounds, particularly in Cornwall, and also in Derbyshire, whence it has received the name of Derbyshire Spar. In Scotland it is very rare; is found only in Aberdeenshire, and, according to Mr Jameson, in the Shetland Islands. From the variety and beauty of its colours, its lustre, and the fine polish of which it is susceptible, it is often formed into vases and other ornamental vessels. The coarser kinds are sometimes used as fluxes to the metallic ores with which they are associated; and it is employed by the chemist to obtain fluoric acid.

SECT. IV.

OF MAGNESIAN FOSSILS.

UNDER the magnesian genus of fossils are comprehended, not only those in which magnesia is the ingredient which is present in largest proportion, but those also in which, though in smaller proportion, there exist the characters in some measure peculiar to the genus. These are softness, and an apparent unctuousity; the greater number of the magnesian fossils being possessed of these, and being, in general, destitute of the hardness, lustre, and transparency, which are conspicuous in many of those which belong to the siliceous and argillaceous genera. It may deserve to be remarked, that almost all the magnesian fossils have a green colour more or less deep.

What has been named Native Magnesia appears, from the analysis of it by Dr Mitchell, by whom it was found in Moravia, to be a carbonate, consisting of magnesia and carbonic acid, in nearly equal parts. It occurs in tuberosc pieces, of a yellowish-grey colour, without lustre or transparency: its fracture is conchoidal, or splintery: it is soft, feels a little meagre, and adheres a little to the tongue.

The substance which has received from the German mineralogists the name of Meerschäum, appears to consist of magnesia united with silex, with a portion of carbonic acid, and a trace of lime; the proportions, in one variety analysed by Klaproth, being silex 50.5, magnesia 17.25, lime 0.5, water 25, carbonic acid 5; in another, silex 41,

magnesia 18.25, lime 0.5, water and carbonic acid 39. Its colour is yellowish-white, with frequently a shade of grey, yellow, or red, without any lustre, but acquiring it in the streak: its fracture is earthy, passing into conchoidal: it is soft, feels a little greasy, and adheres to the tongue: its specific gravity is 1.6. It is not melted by the heat of the blowpipe; nor does it effervesce with acids. This is the substance of which the large Turkey tobacco-pipes are formed. It is found principally in Asia Minor, and in the Grecian islands; and is said to be quite soft when first dug from its repository.

STEATITE, named also Soap-Rock, from its peculiar consistence, and from feeling soapy, occurs massive, disseminated, and, as is also affirmed by mineralogists, crystallized in six-sided prisms acuminated by six planes, and likewise, as has been described, in some other forms. The crystals are very rare; and the supposition of Brochant, that they are pseudo-crystals, is not improbable. The colour of steatite is greyish, greenish, or reddish, white, passing sometimes into similar colours of deeper shades; the external surface is sometimes somewhat shining, as is also the streak; but internally it is dull: it is translucent on the edges: its fracture is uneven, or coarse scaly: it is soft, or very soft; feels unctuous; does not adhere to the tongue: its specific gravity is 2.6. It does not melt before the blowpipe, but becomes white and very hard. The proportions of its constituent parts vary. One variety from Cornwall, analysed by Klaproth, gave silex 48, magnesia 20.5, argil 14, oxide of iron 1, water 15.5; another, from Bareuth, silex 59.5, magnesia 30.5, oxide of iron 2.5, water 5.5. It is sometimes used in the manufacture of porcelain.

There are some fossils very similar to steatite in external properties, and which have usually been considered as allied to it, which, it is singular, are found to contain no magnesia. Such is the Plastic Stone, or Figure Stone of China, analysed by Klaproth; the Bildstein or Axestone of the Germans, analysed by Vauquelin; and the Oriental Jade, analysed by the younger Saussure. All these are composed principally of silex, with argil or lime.

POTSTONE is a fossil allied to steatite. It occurs massive; is of a grey colour, passing into green, or sometimes with a shade of red. Its internal lustre is weakly shining: it is opaque or translucent on the edges. Its fracture is curved foliated, or imperfectly slaty: it is soft; feels unctuous: its specific gravity is 2.8. It is infusible before the blowpipe, and hardens in the fire. According to an analysis of it by Wigleb, it consists of silex 38.12, magnesia 38.54, argil 6.66, lime 0.41, iron 15.02, with a minute trace of fluoric acid. It has been employed among savage tribes in forming vessels for preparing food, whence its name.

SERPENTINE derives its name from the variegated disposition of its colours. The principal colour is green, but with this are intermixed, in stripes or specks, various other colours, particularly red, sometimes yellow, or frequently green, of a different shade from that which forms the ground. It has no lustre, though it acquires it when polished; is also without transparency, or at least is only faintly translucent on the edges. Its fracture is splintery, or fine grained, uneven: its hardness such that it is easily scratched by the knife: its specific gravity is 2.6. It feels soft, but with little unctuousity. It always occurs massive,

and forms entire rocks. Before the blowpipe it remains infusible. By a strong heat it is hardened, and becomes red. Serpentine consists of silex and magnesia, with a portion of iron. In some varieties argil is present; in others, according to Klaproth, it is wanting. The following proportions are given by Kirwan, from an analysis by Knock, silex 45, magnesia 33, iron, so slightly oxidized as to be magnetic, 14, carbonate of lime 6.25, with a trace of argil, muriate of magnesia, and a little water.

The precious or noble serpentine has been distinguished from the common as a sub-species: it has more lustre and transparency: its fracture is conchoidal.

The fossil named Schillerstone was formerly considered as a variety of hornblende; it is regarded by Werner as allied to serpentine. It occurs massive or disseminated, or imbedded in serpentine. Its colour is green, generally dark, with sometimes a shade of yellow: its lustre is shining and semi-metallic; and varies according to the position with regard to incident light: it is translucent on the edges: its fracture is foliated: it is soft, and a little unctuous: its specific gravity is 2.8. It hardens at a very intense heat, and, when borax is added, is fused before the blowpipe. According to Gmelin's analysis, it consists of silex 43.7, argil 17.9, magnesia 11.2, iron 23.7; according to that by Drapier, of silex 41, magnesia 29, argil 3, lime 1, oxide of iron 14, and 10 of water.

CHLORITE.—This fossil has been placed under the argillaceous class; but the proportion of magnesia it contains is greater, and in its general characters it is sufficiently allied with the magnesian fossils: it is also often connected with them. There are different varieties of it, varying

principally in the state of aggregation. Common Chlorite occurs massive and disseminated, often in quartz. Its colour is dark-green : its lustre is weakly shining, and somewhat greasy ; and it is opaque. Its fracture is earthy, or fine foliated : it is easily scratched by the knife ; feels meagre, or very slightly unctuous. According to an analysis of it by Hœpfner, it consists of 41.5 of silice, 39.4 of magnesia, 6.1 argil, 1.5 lime, 10 iron, and 1.5 water. What has been named Foliated Chlorite, from its fracture, which is curved foliated, occurs not only massive and disseminated, but also crystallized in six-sided tables, which are often aggregated or grouped : its colour is dark-green ; its lustre shining and pearly, inclining to resinous : it is translucent on the edges ; is soft, and feels rather unctuous. It consists, according to Lampadius, of silice 35, magnesia 29.9, argil 18, oxide of iron 9.7, water 2.7. Chlorite Slate, distinguished by its slaty fracture, forms a mountain-rock : its colour is dark-green : its internal lustre is weakly shining, and resinous : it is opaque ; is soft, and feels unctuous : it sometimes passes into the other slates, and is distinguished by often containing imbedded, magnetic iron ore in octahedral crystals. The last of these varieties of this species is that which, from its state of aggregation, is named Earthy Chlorite : it is composed of small scaly particles, or is quite loose ; with little lustre ; of a dark-green colour ; feels rather greasy ; and when breathed on, gives an earthy smell. According to Hœpfner, it consists of magnesia 43.7, silice 37.5, argil 4.1, lime 1.6, and iron 12.9. What has been named Green Earth, and which occurs so generally incrusting the agate balls found in amygdaloid, or filling the cavities of the rock it-

self, is very similar in its properties to the earthy chlorite, and may be regarded as a variety of it, containing, perhaps, more argil.

TALC, the characters of which as a magnesian fossil are well marked, occurs massive, disseminated, and in small tabular crystals, confusedly grouped. Its colour is light-green, with frequently a shade of yellow : its lustre is resplendent ; is pearly, or sometimes semi-metallic : it is translucent or transparent in thin leaves : its fracture is straight and curved foliated : the plates into which it is divisible are flexible, but not elastic,—a character by which it is distinguished from mica, as it is also by being very unctuous to the touch. Its specific gravity is from 2.7 to 2.8. It is infusible before the blowpipe, but is melted in the heat excited by oxygen gas. It consists, according to its analysis by Höpfner, of silice 50, magnesia 44, and argil 6. What is named Indurated Talc occurs massive, forming entire strata : its fracture is slaty ; it is less soft and greasy than the common talc, and has much less lustre. The Earthy Talc occurs loosely indurated in small scales of a pearly lustre ; friable ; soiling a little, and feeling rather unctuous. To this probably belongs the *Craie de Briançon*, or French Chalk. Vauquelin found it to be composed of silice 61.25, magnesia 26.25, water 6, argil 1, oxide of iron 1, lime 0.75.

ASBESTOS.—Under this species several varieties are arranged. Common Asbestos occurs massive : its colour is green, of various shades, with intermixture of grey : its internal lustre is weakly shining, and somewhat silky or pearly ; and it is translucid on the edges : its fracture is distinctly fibrous or radiated ; the fibres being parallel,

and either straight or curved: its fragments are long splintery: it is soft, or semi-hard, so as to be easily scratched; and its fibres are rigid: it feels a little unctuous: its specific gravity is 2.5. It melts, though with difficulty, before the blowpipe. In composition it varies considerably: silex, magnesia, and iron, appear to be the essential ingredients; the first, according to an analysis by Wiegleb, amounting to 46.66 parts; the second to 48.45; and the third to 4.79.

AMIANTH.—This name is given to the asbestos when its texture is more delicately fibrous, so that the fibres are easily separated, are fine and perfectly flexible. It has in this state more lustre than when more compact and indurated; the lustre being pearly or silky: it is faintly translucent: its colour is generally lighter than the asbestos, and sometimes it is nearly silvery-white. It is melted with difficulty by the flame of the blowpipe. In composition, it appears to differ from asbestos in containing more silex. From an analysis of it by Mr Chenevix, the results were silex 59, magnesia 25, lime 9, argil 3, iron 2, with 1 of loss. It is this substance which was employed by the ancients to form an incombustible cloth to collect the ashes of the dead on the funeral pile.

Ligniform Asbestos, is that variety in which in texture there is some resemblance to wood: its colour also is wood-brown, of various shades.

The name of Mountain Cork has been given to another variety, from its resemblance in texture, feel, and lightness, to a piece of cork. It is in flat pieces, generally of a grey colour, without any lustre, and opaque: its fracture is fibrous; the fibres being fine, short, and gene-

rally interwoven : it is very soft, so as to be impressed by the nail ; is a little flexible : it feels meagre, and is so light as to float on water ; its specific gravity being from 0.68 to 0.99. It melts, even in minute fragments, with difficulty before the blowpipe. According to Bergman, it consists of silex 56.2, magnesia 26.1, argil 2, lime 12.7, iron 3. When its texture is more close, and it occurs in thinner pieces, it is named Mountain Leather.

ACTYNOLITE.—Of this species there are three varieties, —the asbestous, the common, and the glassy actynolite. The first connects it with the preceding species, to which it has sometimes been referred. It occurs massive, or more rarely in capillary crystals. Its fracture is fibrous or radiated ; the fibres being generally scopiform divergent : its usual colour is greenish-grey, sometimes with shades of red or yellow : its internal lustre is more or less shining, and is silky : it is opaque, or, at most, translucent on the edges ; is soft : its specific gravity is from 2.5 to 2.9. It melts before the blowpipe into a black or grey scoria.

The Common Actynolite occurs massive and crystallized ; its crystals being rhomboidal six-sided prisms, long, frequently acicular, and generally imbedded : its colour is green, usually dark. the external lustre is more or less resplendent and vitreous : its crystals are transparent, or semi-transparent ; the massive translucent, and this often on the edges only : its fracture is diverging radiated : it is sufficiently hard to scratch glass ; is brittle : its specific gravity is from 3 to 3.3. According to Bergman, it is composed of silex 64, magnesia 20, argil 2.7, lime 9.3, iron 4. It melts before the blowpipe into a blackish scoria.

The third variety is the GLASSY ACTYNOLITE.—It occurs massive, or in aggregated acicular crystals : its colour is green of various shades, passing into greenish-white : its lustre is shining and vitreous : it is translucent : its fracture is fibrous or radiated : its fragments are splintery and sharp : it is brittle, and moderately hard ; its specific gravity is 2.9. It melts at a high heat into a glass.

The Granular Actynolite of Werner is the fossil which was named Smaragdite by Saussure. It is of a grass-green colour ; is slightly translucent ; internally shining : its fracture is foliated. It occurs usually imbedded in compact feldspar.

The Glassy Actynolite forms the connecting link with the next species, the Tremolite, which, like the preceding one, comprehends three varieties,—the Asbestous, the Common, and the Glassy Tremolite. The first occurs massive, or in acicular crystals ; its colour is white, with slight shades of yellow, red, or green : its lustre is weakly shining, and silky ; and it is translucent on the edges : its fracture is fibrous ; the fibres being straight, and generally diverging ; its fragments are splintery ; it is very soft, and brittle. The second of these varieties, the Common Tremolite, occurs massive, or crystallized in oblique four-sided prisms, bevelled or truncated on the lateral edges, and promiscuously aggregated. Its colours are greenish, greyish, reddish, or yellowish white : its lustre is more or less strongly shining and pearly : it is translucent, or semi-transparent : its fracture is radiated ; the rays being divergent or interwoven : it is hard, so as to scratch glass ; is brittle, and somewhat meagre to the touch : its fragments also are sharp ; its specific gravity

about 3.2. The third variety, the Glassy Tremolite, occurs massive, or crystallized in slender prisms, aggregated: its colours are the same as those of the preceding varieties; its lustre, which is more or less shining, is vitreous, passing to pearly; it is translucent; its fracture is radiated, or fibrous; the fibres being arranged in diverging groupes: it is semi-hard, brittle, and harsh to the touch.

The varieties of tremolite are often possessed of the property of phosphorescence, so that a moderate heat, or the slightest friction, produces a luminous appearance. From the observations of Bournon*, it appears, that this property does not invariably belong to them, as had been supposed, but that it often depends on the intermixture of the stone, (which is a variety of carbonate of lime, or dolomite), in which they are usually imbedded. It cannot always, however, be referred to this cause, as it is often possessed in a high degree by the tremolite imbedded in other fossils,—for example, in basalt. The composition of this fossil does not appear to be determined with accuracy. A variety analysed by Klaproth gave silex 65, magnesia 10.33, lime 18, oxide of iron 0.16, water and carbonic acid 6.5. If the fossil analysed by Dr Kennedy† were a tremolite, as has been supposed, from its high phosphorescence, and some of its other properties, the proportion of lime is still greater, amounting to 32, with 51.5 of silex, with only a trace of magnesia, and about 8 of soda. On the other hand, in some crystals of non-phosphorescent tremolite, selected by Bournon, and

* Nicholson's Journal, vol. ii. p. 290.

† Edinburgh Philosophical Transactions, vol. v.

analysed by Mr Chenevix, the proportion of lime did not exceed four parts in 100 ; and the large proportion of lime or of argil sometimes found in it is, according to Bournon, derived from intermixture of the calcareous or argillaceous stone in which the tremolite is imbedded.

Sulphate of magnesia occurring native, requires to be noticed under this genus. It appears as an efflorescence on a number of rocks, probably those which contain magnesia and sulphur, from which it is formed by the action of the air.

SECT. V.

OF ARGILLACEOUS FOSSILS.

No common character can be assigned to the genus of argillaceous fossils ; the gems distinguished by their transparency, lustre, and hardness, are comprised under it, equally with the dull and plastic clays. They are connected entirely by their chemical relations.

The Gems had been placed among the siliceous fossils, as in some measure allied with them in external characters, and silex had been supposed to be their principal ingredient. Bergman first shewed the error of this opinion, and proved, by analysis, that in the emerald, sapphire, topaz, ruby, and hyacinth, argil predominates ; their other constituent principles, as discovered by his analysis, being silex, lime, and oxide of iron *. Still, however, the old prejudice prevailed, and they have been generally ranked by mineralogists under the siliceous genus.

* Chemical Essays, vol. ii. p. 75.

The specific distinctions of these fossils were not less obscure. They were perplexed by the distinctions of the jewellers, drawn from very vague notions. The colour, in particular, being the property in which the gems differ most obviously, and which frequently gives them their mercantile value, served as a ground of distinction : hence the ruby, the sapphire, and the topaz, were considered as different, though essentially the same. Another circumstance added to the confusion thus introduced : Other fossils, bearing a resemblance to these gems, had been classed with them, but, being inferior in lustre, transparency, and hardness, in order to distinguish between them, the epithet Oriental was applied to those which were most perfect* ; and, by this contrivance, fossils were classed under one name, and regarded only as varieties of one species, which were totally different. The Oriental and the Saxon topaz, for example, were regarded under this point of view, or as varieties of one species, to which the common name of Topaz belonged, though they are fossils altogether distinct. From these two circumstances, fossils were separated which ought to have been associated, and others were combined which were specifically different ; and it has required much mineralogical discussion to disentangle the perplexity, and establish the proper species,

* The real gems being generally imported from the East, this name of Oriental was given to them ; but it soon came to denote rather that superiority in lustre, transparency, and hardness, which characterized these gems, than the place where they were produced ; or it became rather a distinction of character than of geographic origin.

Rome de L'Isle threw the first ray of light on this subject, by disregarding the colour, and attending rather to the form of crystallization; in consequence of which he arranged together the principal gems named oriental, under the title of Oriental Ruby. Werner also has placed them under one species, to which he gives the name of Sapphire. Haüy has adopted the same arrangement, distinguishing the species by the name of Télésie; and more lately, Bournon has still farther extended the relations of these fossils, by connecting them with the Corundum, a fossil which had been brought from India, and which, analysed by Klaproth, was found to be composed principally of argillaceous earth. This having in general little transparency or lustre, Bournon names Imperfect Corundum, while the other variety, possessing these qualities, and comprising the oriental gems, is distinguished by the appellation of Perfect Corundum*. These arrangements have received the sanction of chemical analysis. The skill of Klaproth, of Vauquelin, and Chenevix, has been exerted in investigating the composition of these fossils, and they have been proved to be argil nearly pure.

PERFECT CORUNDUM, the Sapphire of Werner, the Télésie of Haüy, occurs in fragments, and crystallized; the forms of its crystals being the double three-sided pyramid, the single six-sided pyramid, and the six-sided prism, variously modified by truncations and acuminations. Its colours are numerous,—blue, green, red, of numerous shades, and yellow or yellowish-white, and

* Philosophical Transactions, 1802, p. 233.

sometimes more than one colour is present even in the same crystal. It is more or less transparent : its lustre is resplendent and vitreous ; and it often presents a beautiful reflection of light in the form of a star : the fracture is conchoidal, or imperfectly foliated : the hardness inferior to that of the diamond, but superior to that of every other fossil, and not yielding to the file : the specific gravity is from 3.9 to 4.1.

The distinctions from colour, forming the different oriental gems, have been already noticed. The red colour constitutes the oriental ruby ; the blue, the sapphire ; the yellow, the topaz ; the purple, the amethyst ; the green, the emerald ; the yellowish-green, the chrysolite. It is only necessary to remark, that there are gems, to which several of these names likewise belong, distinguished by the epithet Occidental, which are altogether different.

These fossils are not fusible by the blowpipe, nor even by the more intense heat of a burning mirror, but are melted by the heat excited by a stream of oxygen gas directed on burning charcoal. They are generally phosphorescent from friction.

The variety of a blue colour, the Oriental Sapphire, analysed by Klaproth, was found to be composed of 98.5 of argil, 1 of oxide of iron, and 0.5 of lime : it is argil, therefore, nearly pure. Analysed by Chenevix, it gave argil 92, silice 5.25, iron 1 ; there being 1.75 of loss. The red variety, or the Ruby, afforded to the same chemist 90 of argil, 7 of silice, and 1.2 of iron*.

These gems are found principally in India, and in the

* Philosophical Transactions, 1802, p 327.

island of Ceylon. Some varieties of them have also been found in Bohemia, in Portugal, and in the stream of Expailly, in France.

IMPERFECT CORUNDUM, or, as it is generally named simply, Corundum, is a fossil which has been brought within these few years from India, where it appears to have been long used, from its great hardness, for polishing hard stones. It occurs massive, disseminated, and crystallized; the forms of its crystals being the same as those of the perfect or transparent corundum. Its colour is greenish-white, frequently with a shade of grey, and sometimes of red: the crystals are extremely dull and rough, and are nearly opaque, or at most translucent: the internal lustre is more or less shining, and nearly vitreous: the fracture is foliated; the fragments rhomboidal: it is very hard, but rather less so than the perfect corundum: its specific gravity is 3.7 or 3.8. It loses a little of its colour when strongly heated, but is not fused by the flame of the blowpipe on charcoal, even when soda, or borax, is added to it.

The analysis of this fossil was found extremely difficult by Klaproth, from the very strong aggregation of its particles; and from this circumstance he was so far misled, as to be disposed to conclude, that it was composed in part of a new species of earth, the characteristic quality of which appeared to be, perfect insolubility in acids, or in alkalis. Subsequent investigation, however, discovered to him this error, and, according to his second analysis, one variety from China is composed of 84 of argil, 6.5 silix, and 7.5 oxide of iron; another from Bengal, of 89.5 argil, 5.5 silix, and 1.25 oxide of iron. Mr Chenevix, in

different specimens, found the proportion of argil to be 86.5, 87, or 91,—that of silex to vary from 5 to 7, and of iron, from 1.5 to 6.5. One variety of a light purple colour, analysed by Mr Gregor, appears to have contained about 4 parts of oxide of titanium in 100 parts *.

The DIAMOND SPAR, which has been distinguished from corundum, appears to be a variety of it. It is of a brown colour, and its internal lustre is splendid and pearly.

These fossils have been supposed to occur only in the east of Asia. From the observations of Bournon, corundum seems to have been found in France, and, according to Pini, it is found in Italy †. Other localities that have been assigned to it are doubtful.

The fossil substance which has been known by the name of Emery is of the same family. It occurs only massive, or disseminated : is of a grey colour, more or less dark : its lustre is weakly shining : and it is only slightly translucent on the edges. Its fracture is fine grained uneven : it is as hard as corundum, or nearly so, and is used, from this quality, for the same purposes, and particularly for polishing the metals. According to Mr Tennant, the emery of the isle of Naxos is composed of 86.5 of argil, 3 of silex, and 4 of iron ‡. According to Vauquelin, the emery of Jersey consists of 65 of argil, 4 of silex, 1 of lime, and 24 of iron; and this iron appeared to be rather mechanically mixed, than intimately com-

* Nicholson's Journal, vol. iv. p. 209.

† Ibid. vol. xi. p. 103.

‡ Philosophical Transactions, 1802, p. 401.

bined. Emery, therefore, he considers as corundum contaminated with iron*.

To a species, distinguished by the name of Spinelle, have been referred the gems known by the names of Spinell, and Balass Rubies, and by these names distinguished from the oriental ruby. They approach to it, however, in external characters, and in chemical composition. The spinell occurs in grains, and crystallized; the form of its crystals being the octaedron, perfect, or variously modified by truncation and acumination. Its colour is red, of various shades: the deep crimson-red forms the spinell ruby; the pale rose-red the balass ruby: it passes also into blue, and into yellow or brown: its lustre is resplendent and vitreous: it varies from translucid to transparent: its fracture is conchoidal, or foliated; it is very hard, but rather less so than the corundum: its specific gravity is from 3.5 to 3.7. It does not melt alone before the blowpipe, but is fused by the aid of borax. According to Klaproth, it consists of 74.5 of argil, 15.5 of silex, 8.25 of magnesia, 1.5 oxide of iron, 0.75 lime; according to Vauquelin, of argil 82.47, magnesia 8.78, chromic acid 6.18.

The CEYLANITE, as it has been named from being found in Ceylon, the pleonaste of Haiiy, is probably a variety of spinell. It is rather harder, and has less external lustre and transparency. Its colour is dark-blue, its fracture conchoidal.

What has been named the Occidental Topaz, and which is found principally in Saxony, Siberia, and Brazil, deviates

* Annales de Museum National, tom. iv. p. 412.

still more in its composition from the corundum, the proportion of silex becoming greater. It occurs sometimes massive, or in fragments, more frequently crystallized: the form of its crystals being the oblique tetraedral prism, variously modified. Its colour is yellow, which passes by various shades into white, grey, pale-green, blue, and red: its lustre is resplendent and vitreous: it varies from transparent to translucent: its cross fracture is foliated: its longitudinal fracture conchoidal: it is very hard, but rather less so than the spinell: its specific gravity is 3.5. This fossil becomes electric by heat. It is infusible before the blowpipe, but melts when borax is added. When heated in a crucible, the Saxon topaz becomes white, the Brazilian red; the latter thus altered is sometimes sold under the name of Brazilian Ruby. The Saxon topaz was found by Vauquelin to consist of 68 of argil, 31 of silex; but, by a subsequent analysis, he discovered fluoric acid in it, as well as in the Brazilian topaz.

CHRYSOBERYL is a species which may be considered as allied to these, and which is altogether different from the chrysolite with which it had been confounded. It occurs in grains, and crystallized under the forms of the six-sided table with the edges truncated, and the double six-sided pyramid. Its colour is pale-green, with frequently a shade of yellow; and it often exhibits a milk-white opalescence: its internal lustre is resplendent, and approaching to resinous: it is semi-transparent: its fracture is conchoidal: it is so hard as to scratch glass: its specific gravity is 3.7. It is not melted by the blowpipe. Klaproth found it to be composed of argil 71.5, silex 18, lime 6, oxide of iron 1.5, with 3 of loss. It is found in Brazil

and Ceylon, and, in commerce, has been known by the name of Oriental Chrysolite.

CYANITE.—This fossil has been placed as a species under the magnesian genus ; but the portion of magnesia it contains is extremely small, while argil is the chief ingredient, and, in external characters, it is as much connected with the argillaceous as with the magnesian fossils. It occurs massive, disseminated, and crystallized ; the crystals being oblique, flat, tetraedral prisms, truncated on the lateral edges. Its principal colour is blue, whence its name has been derived ; but it also occurs white and grey : its lustre is shining and pearly : it is generally translucent ; sometimes transparent. Its fracture is radiated ; that of the crystals foliated : its fragments are splintery, and wedge-shaped : it is semi-hard, scratches glass, but is scratched by quartz : its specific gravity is 3.5. It remains perfectly unaltered before the flame of the blow-pipe, even when excited by oxygen gas. It consists, according to the younger Saussure, of argil 55, silix 29.2, lime 2.25, magnesia 2, oxide of iron 6.65, with 4.9 of loss.

LEPIDOLITE.—This fossil occurs massive : the mass is of a purple colour, but presents silvery white scales, of a pearly lustre : it also sometimes occurs of a grey colour : it is translucid on the edges : its fracture is small-grained uneven : it is soft, so as to be very easily scratched by the knife : its specific gravity is 2.8. It melts with great ease before the blowpipe, with intumescence, into a white pearly-like matter. It loses its colour in a red heat. Klaproth found it to be composed of silix 54.5, argil 38.25, oxide of manganese and iron 0.75, potassa 4, with 2.5 of loss, partly from the escape of water. The result of an

analysis by Vauquelin is considerably different, being silex 54, argil 20, oxide of iron 1, oxide of manganese 3, potassa 18, fluate of lime 4.

MICA.—This fossil is an important one, from its extensive distribution, especially as an ingredient in several of the principal aggregate rocks. Its characters are also very appropriate. It occurs disseminated, in thin plates, and sometimes, though rarely, crystallized; the crystals being six-sided tables, and six-sided prisms: its colour is grey, but with various tints of brown, black, green, and red: the lustre of the surface of its plates is resplendent, and even metallic: in the thin plates into which it is divisible it is transparent, but in mass is only translucent, and often even on the edges only: its fracture is distinctly foliated; and it is very easily split into thin plates, which are somewhat flexible and elastic: its hardness is such, that it can be scratched by the nail: it feels smooth, but not unctuous: its specific gravity is from 2.7 to 2.9. Before the blowpipe it melts, though with much difficulty, into a grey enamel. It is composed, according to Bergman's analysis, of argil 46, silex 40, magnesia 5, oxide of iron 9; according to Vauquelin's, of silex 50, argil 35, oxide of iron 7, lime 1.33, magnesia 1.35, with 5.32 of loss. Kirwan found 20 parts of magnesia in 100 of colourless mica.

Mica is one of the essential ingredients of granite, and often exists in it in large plates. Gnesis, which is only granite of a slaty texture, appears to derive this peculiarity from the mica; and the aggregate of mica, and quartz alone, in which the mica is still more abundant, forms the micaceous shistus, or mica slate. Mica is also some-

times contained in porphyry, in wacke, and in sandstone : what occurs in the latter is probably derived from the disintegration of the primitive rocks.

HORNBLENDE.—Common Hornblende occurs massive, disseminated, and sometimes crystallized ; its crystals being prisms, aggregated, and intersecting each other. Its usual colour is black, with frequently a tinge of green, and sometimes the green even predominates : its streak is always green, with a shade of grey : its internal lustre is shining, and approaching to pearly : when of a black colour, it is opaque ; when green, it is translucent on the edges. Its fracture is foliated, sometimes also broad radiated : its hardness is such, that it is scratched by the knife ; but it cannot be broken but with difficulty. Its specific gravity is from 3.6 to 3.8. When breathed on, it gives an argillaceous smell. Before the blowpipe, it melts, without difficulty, into a greyish-black glass. The analyses of hornblende have presented different results, and perhaps have scarcely been executed with accuracy. In an analysis performed by Mr Kirwan, he found the composition to be, silex 37, argil 22, carbonate of magnesia 16, carbonate of lime 2, and oxide of iron 23.

What has been named Labradore Hornblende is merely a variety of the former, distinguished principally by its copper-red colour. The Basaltic Hornblende occurs always imbedded in crystals, generally in basalt, sometimes in wacke, or in lava ; the form of its crystals being the equilateral six-sided prism, flatly acuminated by three or four planes, and sometimes thus acuminated only at one extremity of the prism, while it is bevelled at the other : these crystals are usually small : their colour is black ;

their surface smooth; their internal lustre splendid; they are always opaque; the fracture is foliated; it is more easily frangible than common hornblende; in its chemical characters it is the same. Hornblende Slate is distinguished by its slaty fracture; it occurs always massive: its other characters are the same as those of the general species. Common hornblende is an ingredient in a number of aggregate rocks. Associated with feldspar and quartz, and sometimes with mica, it forms siennite; with feldspar, it constitutes grunstein; it is found disseminated in other rocks; and both it and the hornblende slate form large beds or rocky masses.

BASALT.—This, which forms an extensive mountain-rock, is a homogeneous fossil, and constitutes therefore a proper species. Its colour is greyish-black: in the streak, a lighter grey: it is nearly without lustre, or owes any which it exhibits to particles of hornblende: it is opaque, or feebly translucent on the edges: its fracture is usually uneven: it is hard, so as to be scratched by the knife with some difficulty, and sometimes to give feeble sparks with steel; it is not easily frangible: its specific gravity is from 2.8 to 3. It melts easily before the blow-pipe into an opaque black glass; and has been from this quality employed in the manufacture of the coarser kinds of glass. It softens, according to Dr Kennedy's experiment, at from 38° to 45° of Wedgwood. According to the analysis of this rock, executed by this distinguished chemist, it is composed of silice 48, argil 16, oxide of iron 16, lime 9, soda 4, muriatic acid 1, water, and other volatile matter, 5. This analysis has been confirmed by Klaproth, who states the composition of basalt as follows:

silex 44.5, argil 16.75, oxide of iron 20, lime 9.5, oxide of manganese 0.12, soda 2.6, water 2.

Basalt occurs in large beds or masses, forming entire mountains, also in veins. It is distinguished by its tendency to assume the columnar form; the columns being often of a great size, straight, curved, and sometimes articulated. It occurs also in globular concretions. In this country it abounds. Our name of Whin is applied both to it and grunstein, two rocks which are intimately connected.

CLINKSTONE.—This fossil, which is closely related to basalt, and indeed passes into it, has received its name from the peculiar sound it gives when struck. It occurs always massive, and forms beds; and sometimes assumes the columnar form: its colour is grey, with shades of green or yellow; it is dull, or weakly shining, and translucent on the edges. Its fracture is slaty; it is semi-hard, or hard; is easily broken; has a specific gravity of 2.5. According to Klaproth's analysis of it, it is composed of silex 57.25, argil 23.5, oxide of iron 2.25, manganese 0.25, soda 8.10, and water 3. It forms the basis of the rock named Porphyry Slate; crystals of feldspar being imbedded in it.

Wacke is another rock, which appearing to be homogeneous, must also be regarded as a species. It is intimately connected with basalt, and forms an intermediate substance between it and clay. Its colour is greenish-grey, with sometimes shades of brown or red: it has scarcely any lustre, and is opaque; its fracture is even; it is soft, and easily broken; and is very liable to fall into pieces from exposure to the air: its specific gravity is from

2.5 to 2.8. It melts with the same facility as basalt, and is probably of similar composition, containing perhaps more argil, and it may be presumed, from its inferior specific gravity, less iron. It occurs in large beds or masses : often contains organic remains or impressions ; it is often also cellular, its cavities being filled with calcareous spar, &c. when it forms amygdaloid. Mica is also frequently disseminated in it in small scales.

ARGILLACEOUS SLATE, or CLAY SLATE, the primitive slate of some mineralogists, forms very extensive strata in connection with the other primitive rocks, and likewise with those of transition. Its colour is grey, but with various shades of blue, purple, and green ; its lustre is weakly shining, or dull : it is opaque ; its fracture is slaty, or foliated ; the plates being either straight or curved : its fragments are splintery or tabular ; sometimes of a rhomboidal form ; it is soft, so as sometimes to be scratched by the nail ; its specific gravity is from 2.6 to 2.8. It has not been analysed with accuracy, but consists, according to Kirwan, of silex, argil, lime, magnesia, and oxide of iron ; the proportions varying considerably in different specimens. One variety, which he names Anglesea Slate, is composed of silex 38, argil 26, magnesia 8, lime 4, iron 14. When slate splits easily into thin and firm plates, it is used for covering the roofs of houses : when soft, and of a fine grain, it forms the common writing-slates.

Other kinds of slate have been distinguished, with regard to which it may be doubted if they form proper chemical species : they pass into each other ; and the limits of the divisions cannot always be accurately marked. Whet-slate, Novaculite, or Hone-stone, is distinguished from the other slates by its fracture, which is splin-

tery, or scaly ; it is of a greenish colour ; has little lustre ; and is translucent only on the edges ; it feels somewhat greasy. The Drawing Slate is of a greyish-black colour, dull, opaque, and soft, so as to write and soil. It is used in making black crayons. The Alum Slate is that which is distinguished by affording alum. When exposed to the air, it has often an efflorescence of that salt ; its colour is grey ; internally its lustre is only glimmering ; its fracture is slaty ; and its fragments tabular. Bituminous Shale is of a brownish-black colour, with little lustre : its fracture is slaty ; and its fragments are thin, shivery and tabular ; it is very soft, and feels a little greasy. Laid on burning fuel, it gives a weak flame and a black smoke, and loses weight, becoming white ; it appears to consist of clay with bitumen. The Slate Clay forms the transition of these fossils into common clay ; its fracture is more or less slaty, approaching to earthy ; it is opaque, dull, generally of a greyish colour ; is soft ; feels meagre, and adheres to the tongue ; it softens and breaks down in water.

The term Clay, considered as a mineralogical one, is rather ambiguous ; it is applied to those earthy mixtures, more or less indurated, which imbibe water, and may be kneaded with it into a paste somewhat ductile. Argil is the basis of all of them ; or rather it is the earth which gives them their predominating character ; for, in general, silex is present in larger proportion. There are also frequently other ingredients present ; as lime, which communicates fusibility to the mixture ; magnesia, which sometimes gives to it a soapy feel ; and oxide of iron, which is generally the colouring matter ; sometimes,

however, the colour depends on bituminous matter, and such clays burn white. These substances are generally only mechanically mixed, and in variable proportions, so that it is difficult to form precise species, or even varieties. The most general only can be attended to.

Indurated Clay, or Claystone, is clay in the highest state of induration. It occurs massive: its fracture is earthy, passing sometimes into even or slaty: it is soft, but does not adhere to the tongue, or does so very slightly, nor is it easily diffused in water, and it does not form with it a ductile paste: it is dull and opaque: its most common colours are grey and red. It often occurs in strata, sometimes in veins; and it forms the basis of argillaceous porphyry.

The purest clay is that which has been named Porcelain Clay, from the use to which it is applied; it appears, in general, to have originated in the decomposition of feldspar. It occurs loosely indurated, and earthy: its colour is white, with shades of grey, yellow, and red, without lustre or transparency: it feels soft, but not unctuous; does not adhere to the tongue: in water, it falls to powder, and, when kneaded forms a ductile paste. It is, in general, infusible by any heat that can be raised. It consists essentially of silex and argil; but the proportions of these vary considerably. Mr Wedgwood found the porcelain clay of Cornwall to be composed of 60 of argil, with 20 of silex. Hassenfratz, on the contrary, found the fine clay of Limoges to consist of silex 62, argil 19, magnesia 12, and sulphate of barytes 7; and in every situation, probably, its composition varies. The native argil of some mineralogists appears to be merely a variety

of this; the argil being more or less mixed with sulphate or carbonate of lime.

Potters' Clay occurs massive, and often forming strata: its fracture is earthy, and it has no great induration: it is opaque, dull; generally of a yellowish or greyish white colour: it soils, feels soft, and somewhat unctuous; adheres to the tongue; is diffusible in water, and forms with it a ductile paste. Pipe-clay is a variety of this. The clay of which the Hessian crucibles are manufactured, consists, according to Vauquelin's analysis of it, of 69 of silex, 21.5 of argil, charcoal 1, and 8 of oxide of iron. Loam is the same substance, mixed with sand, oxide of iron, and various other foreign and accidental substances. The Boles, which are nearly of the same degree of induration as the potters' clay, and of a red or yellow colour, are of similar composition, and appear to owe their colours to oxide of iron. They are distinguished by their conchoidal fracture. Bergman found their component parts to be, silex 47, argil 21, magnesia 6.2, lime 5.4, iron 5.4, and water 17. The Ochres appear to be similar to the boles, containing only more oxide of iron. Lithomarge is distinguished by its greater fineness, being composed of scaly particles, with a surface more or less smooth and shining: it is soft and mild, feels greasy, and adheres to the tongue. Its colours are white, yellow, red, blue, and grey; and these are often intermixed. It melts into a slag. A variety of this, analysed by Bergman, was found to be composed of silex 60, argil 11, carbonate of lime 5.7, carbonate of magnesia 0.5, oxide of iron 4.7, water 18. Fullers' Earth occurs massive, but little indurated: its fracture is earthy,—sometimes uneven or slaty; without

lustre or transparency : its colours are shades of green, generally light : it is soft and mild, and does not adhere much to the tongue. In water, it falls to powder, without forming a ductile paste. From Bergman's analysis, it appears to be composed of silex 51.8, argil 25, lime 3.3, magnesia 0.7, iron 0.7, water 15.5. Tripoli is found loose or indurated, and has been supposed to be an intimate mixture of clay and sand : its fracture is earthy : it feels harsh and dry ; does not adhere to the tongue, nor soil : it moulders in water, but does not form a ductile paste. It is used for polishing the metals and glass.

NATIVE ALUM, a saline product, is to be regarded as belonging to the argillaceous genus, argil being its base, united with potassa and sulphuric acid, and frequently having in its composition oxide, or perhaps rather sulphate, of iron. It occurs generally as an efflorescence, either in the state of a powder, or in slender silky crystals, and possessed of all the properties of the artificial salt. It is probably formed from the action of air and water on the earthy matter on which it is found.

CRYOLITE.—This is another fossil which, from its composition, might be regarded as of a saline nature. It consists of argil, with soda, combined with a large quantity of fluoric acid. It has, however, no solubility in water, and is quite insipid. It occurs massive, is of a white colour, with not much lustre, and only translucent. Its fracture is imperfect foliated ; it is easily scratched, or broken ; and has a specific gravity of 2.9. It melts before the blowpipe, and then hardens. It dissolves in sulphuric acid with slight effervescence, and the aeriform fluid that escapes, being fluoric acid, erodes glass. It has been

found by Klaproth to consist of fluoric acid and water 40.5, soda 36, and argil 23.5, with which the analysis by Vauquelin almost exactly corresponds. It has been hitherto found only in Greenland.

SECT. VI.

OF GLUCINE FOSSILS.

GLUCINE is an earth which in many of its properties has a close resemblance to argil; and the fossils which can be regarded as deriving their characters from it, have likewise many analogies with the pure argillaceous fossils—the gems. Strictly speaking, it might perhaps be maintained, that no fossils hitherto discovered can be referred to a genus of which glucine is the base; for there are none of which it is the ingredient present in largest proportion. It is now, however, sufficiently established, that the characters of a compound are not always derived from the ingredient it contains in largest quantity; the influence of another in smaller quantity is often predominant, and this appears to be very strikingly the case with regard to this earth in its relation to certain fossils.

Haüy, in attending to the crystalline structure of two gems, the Beryl and the Emerald, had observed a perfect identity in their primitive forms. This led him to suspect an analogy between them in constitution, and Vauquelin submitting them to chemical analysis, discovered in them the earth he named Glucine. There can therefore be little doubt, but that their principal characters are de-

rived from this earth, and that of course they may be placed as species of a genus which it forms, though silex and argil are present in larger quantity in their composition. They afford a very excellent example of the difficulties which still attend the determination of the mineral species from the results of analysis, as they show of how much importance an ingredient may be in a combination, though existing in it in comparatively a small proportion.

The OCCIDENTAL EMERALD forms the species to which the name of Emerald ought to be confined, what is named oriental being a variety of corundum. At present, it is known only to exist in South America, though it appears to have been known to the ancients, specimens of antique emeralds being preserved. It occurs crystallized, in short six-sided equiangular prisms, perfect or truncated on the edges, lateral or terminal, or on the terminal angles. Its colour is that pure and rich green, which has derived from it the name of Emerald Green, which sometimes becomes pale : its lustre is resplendent and vitreous ; and it varies from translucent to transparent : its fracture is small conchoidal : it is hard, but not much more so than quartz, and therefore considerably inferior in this quality to the preceding gems : its specific gravity is 2.6 or 2.7. It is melted, though with difficulty, by the blowpipe into a white glass : it fuses more easily with borax. Vauquelin found the emerald to be composed of silex 64.5, argil 16, glucine 13, oxide of chrome 3.25, lime 1.6, water 2. Klaproth found the same elements in nearly the same proportions ; the oxide of chrome amounting only to 0.25, and there being 1 of oxide

of iron. The emerald is highly valued as a gem, though it is difficult to procure it of a pure and uniform colour.

BERYL.—This fossil is so analogous in properties and composition to the emerald, that it may be doubted if they are not varieties of the same species. Chrome has not been discovered, however, in the composition of the beryl; and to this is probably to be ascribed the absence of the rich green colour of the emerald. Its colour is pale green, which passes through various shades, on the one side into blue, on the other into yellow. It occurs in crystals of the same forms as the emerald, only the prism is long; and its lateral planes are streaked; its terminal planes smooth: while in the emerald it is just the reverse: their lustre is shining and vitreous; and they are usually transparent: the fracture is imperfectly conchoidal: the hardness superior to that of quartz, and nearly equal to that of the topaz: the specific gravity is 2.6 or 2.7. The beryl is melted with difficulty before the blowpipe alone, but easily when borax is added. It becomes strongly electrical from friction. According to Vauquelin's analysis of the beryl, it is composed of silex 68, argil 15, glucine 14, lime 2, and oxide of iron 1.

With these species, the fossil from Peru, which has received from Haüy the name of Euclase, is connected, its composition being similar to that of the beryl; its analysis, according to Vauquelin, affording silex 36, argil 19, glucine 15, iron 3, with 27 of loss. It occurs crystallized in six-sided prisms, which are singularly modified by truncation, bevelling, and acumination. Its colour is green; its lustre resplendent and vitreous: it is transparent: the fracture is foliated; the hardness superior

to that of quartz, with much brittleness ; the specific gravity 3.0. It first loses its transparency before the blow-pipe, and then melts into a white enamel.

SECT. III.

OF SILICEOUS FOSSILS.

THE siliceous fossils can scarcely be distinguished by any common characters ; for although many of them are possessed of great lustre, transparency, and hardness, these qualities are not possessed by all of them, nor are they peculiar to them, but are possessed in an equal or higher degree by some of the fossils belonging to other genera.

QUARTZ is the species that may be placed at the head of the genus, as consisting almost entirely of silex. Analysed by Bergman, it was found to be composed of 93 of silex, 6 of argil, and 1 of oxide of iron. When perfectly transparent, it has been named Rock Crystal,—a distinction of no importance, and which it is unnecessary to observe. It occurs crystallized : the perfect form of its crystals appears to be the six-sided prism acuminate at both extremities by six planes, set on the lateral planes ; sometimes the prism is wanting, or nearly so, and then the form is the double six-sided pyramid, the remaining part of the prism forming a truncation on the common base ; and frequently the single six-sided pyramid only is apparent. It occurs also often massive, disseminated, and of a variety of external shapes. Its most frequent

colour is white, which has various shades of other colours : it also occurs brown, and more rarely yellow and red. Its lustre is highly vitreous : it is perfectly transparent, semi-transparent, or sometimes only translucent. Its fracture is splintery, or conchoidal ; sometimes even imperfectly foliated, and sometimes presents distinct prismatic concretions : its fragments are sharp-edged : it is hard, so as not to be scratched by the knife, and to give sparks with steel : its specific gravity is 2.6. It is infusible before the blowpipe ; and is even imperfectly softened by the intense heat excited by a stream of oxygen gas directed on the flame. It is often phosphorescent, so that when two pieces are rubbed together, they emit a considerable light.

Quartz is a fossil extremely abundant. The transparent crystallized variety, or rock crystal, occurs generally in veins or drusy cavities : the semi-transparent, or common quartz, is not only found in similar situations, but constituting veins, forming even sometimes entire rocks, and abundantly as a constituent part of some of the most important fossil aggregates,—granite, gneiss, mica slate, and others. When transparent, and especially when coloured, it is used as an article of jewellery.

When quartz is of a purple colour, it has received the name of AMETHYST : this variety is also in some measure distinguished by its fracture presenting thick prismatic distinct concretions. It occurs generally crystallized in the internal surface of hollow agate balls or geodes, sometimes also in veins. The real oriental amethyst is a variety of the sapphire.

ROSE QUARTZ, or Milk Quartz as it has been named,

has been placed as a variety of the species. Its colour is rose-red, sometimes milk-white; it is semi-transparent, with a vitreous lustre: its fracture is conchoidal, and it always occurs compact. From its colour, it is used in jewellery.

The fossil which has received the name of **PRASE**, is ranked by Werner as a sub-species of quartz, from which it differs little: its colour is leek-green, of various shades, and it generally occurs massive, rarely crystallized.

The species known by the name of **CHRYSTOPRASE**, is a very pure siliceous fossil, containing, according to Klaproth, in 100 parts, 96.16 of silex, with 0.83 of lime, and 1 of oxide of nickel. Its colour is apple-green, derived probably from the oxide of nickel: it has little lustre; is translucent or semi-transparent: its fracture is even: it is hard, so as not to be easily scratched by the knife: its specific gravity is 3.2. It occurs massive. Before the blowpipe it loses its colour and transparency, but does not melt. It is used for jewellery.

OPAL is a siliceous fossil not less pure. In one variety of what has been named the Noble Opal, Klaproth found the composition to be 90 of silex, with 10 of water: in another of the common opal, the constituent parts were, 94.5 of silex, 5 of water, and 1 of oxide of iron. The noble opal, as it is named, is distinguished by the beautiful play of colours which it exhibits,—green, red, blue, and yellow of numerous shades, varied according to the position. Its proper colour is milk-white, which has a tint of red or yellow when held between the eye and the light: its lustre is splendid and vitreous: it is translucent: its fracture is conchoidal: it is moderately hard, and easily

frangible : its specific gravity is 2.1. It occurs massive, or disseminated, generally in argillaceous porphyry. Before the blowpipe it becomes opaque, but is not melted. The common opal has the same characters, but does not present the beautiful effulgence of colours of the precious opal. The semi-opal has less lustre and transparency, is more dense, hard, and heavy, and occurs not only massive, but of various imitative shapes : it contains a large proportion of oxide of iron, not less, in one variety analysed by Klaproth, than 47 in 100 parts. Wood opal is supposed to be wood penetrated with the matter of opal : its fracture shews the former ligneous texture, and the forms of its masses likewise demonstrate its origin. It is intermediate in its characters between the common opal and the semi-opal. All these fossils are found principally in Hungary, and the precious opal is exclusively the produce of that country. This variety of the opal, from the beauty of its colours, is considered as a gem, but its value is much diminished by its softness and brittleness : it is difficult to meet with it perfect, but in small pieces.

Some varieties of opal, which appear to have lost the water they contain from exposure to the air, and in consequence of this have become opaque, recover their transparency when immersed in water. These have been named Hydrophanes. The Girasol of some mineralogists appears to be a variety of milk-white common opal. The Hyalite, or Muller's Glass, which occurs disseminated in wacke, of a white colour and glassy lustre, appears to be a variety of the common opal ; as the Menelite, which occurs imbedded in tuberosc masses, in adhesive

slate at Menil-montant near Paris, is of the semi-opal: their analysis gave to Klaproth nearly the same results. The fossil which has received the name of Cat's Eye, from its property of reflecting in certain directions a changeable whitish effulgence similar to the eye of a cat, appears likewise to belong to the same family; its external characters being not only similar, but its composition, as determined by Klaproth, being nearly the same as that of the common opal.

CHALCEDONY is a species which, in its external characters, has relations with the preceding fossils, and in composition does not differ greatly from them, being composed, according to Bergman, of 84 of silex and 16 of argil; according to Guyton, of 86 of silex, 4 of argil, 1 of lime, and 7.6 of oxide of iron. It occurs massive, frequently in nodules in rocks, botryoidal, stalactitic, and in other imitative shapes, sometimes also in veins. Its colours are very various, white, with shades of blue: grey, and yellow, are most common; and these colours are often arranged in stripes parallel or concentric: it has not much lustre, though it is susceptible of a fine polish, from which lustre is acquired: it is generally semi-transparent or translucent: its fracture is even: it is hard, so as to strike sparks with steel: its specific gravity is 2.6. It is infusible before the blowpipe.

CARNELIAN has been distinguished from chalcedony as a sub-species. Its usual colour is red of various shades, which sometimes passes into reddish-white, yellow, or even milk-white; its fracture is perfectly conchoidal, and it has rather more lustre than chalcedony. In their other characters they are the same. Cacholong is chalcedony

of a milk-white colour. The name of Onyx is given to that variety of chalcedony in which stripes of different colours alternate. When one of these colours is red, it has been named Sardonyx. When chalcedony is stained with dark-coloured spots, veins, or arborizations, it forms the Mocho stone.

To this species may also be referred the greater number of AGATES, as chalcedony is generally their basis. Strictly speaking, the agate is an aggregate fossil, consisting of chalcedony, carnelian, jasper, quartz, or flint; two or more of these being variously intermixed, but so that they are always perfectly distinct. Like chalcedony, agates are generally found in nodules, and in rocks of a similar kind,—those of argillaceous porphyry, and amygdaloid, sometimes also in veins. Numerous varieties of them are formed from their constituent parts, as chalcidonic agate, jasper agate, &c.; or from the diversified appearances they present, as landscape agate, fortification agate, ribband agate, moss agate, eyed agate, &c. The central part of the agate nodule is often hollow, or imperfectly filled; and in this case a crystalline arrangement is observed, or even regular crystals of amethyst or quartz are formed.

Chalcedony, under all these forms, is much valued for cutting into seals, and various ornaments. It is better adapted to this purpose than almost any other kind of stone, as, along with a great degree of hardness, which prevents impressions on its surface from being injured or worn down, it has a degree of tenacity, by which it is not liable to break off in splinters during the cutting; and hence figures of much greater delicacy can be exc-

cuted on it than on any other. It is also susceptible of a very fine polish; and the variety and disposition of its colours render it highly beautiful.

FLINT.—This, as has been already stated, is a very pure siliceous fossil; the silex in its composition amounting to 97 or 98 in 100 parts, with minute traces of argil, lime, and oxide of iron, and, according to Dolomieu, about two parts of water. Its characters are very appropriate. It occurs generally in nodules, imbedded in chalk or limestone: these nodules have often the impressions of organic beings, or form the substance of petrifications: its usual colour is grey, which is of various shades, and passes into yellow, and brown or black; and the different shades are often intermixed: its internal lustre is weakly shining; in thin pieces it is translucent: its fracture is very perfectly conchoidal; its fragments sharp-edged: its hardness is such, that it gives copious sparks with steel: its specific gravity is 2.5. It is infusible before the blow-pipe, but loses its colour. It is phosphorescent from friction. Its uses for striking fire with steel, and in the manufacture of the finer kinds of glass and porcelain, are well known.

What has been named Flint Slate, or Siliceous Schistus, approaches to flint in colour, lustre, degree of transparency, hardness, and other characters. Its fracture, however, is slaty, and it occurs in large masses, forming even entire beds. The Lydian Stone, or touchstone, by which the purity of gold or silver is determined, is a variety of this fossil.

HORNSTONE, or PETROSILEX, likewise occurs in large beds, and in particular forms the basis of one variety of

porphyry. Its colour is grey, of various shades : it is dull, and only translucent on the edges : its fracture is splintery : in one variety it is conchoidal : its fragments are sharp-edged. Like the preceding fossils, it is infusible before the blowpipe, and, according to Kirwan's analysis, it contains more argil : it thus, both in external character and in composition, forms the transition from them to jasper. Under this species is placed by Werner, as a variety, the siliceous petrified wood, or Woodstone as it is termed ; which he regards as composed of the matter of hornstone, introduced, by slow infiltration, into the substance of wood, while the vegetable matter, by a slow decomposition, has been removed. It retains the appearance of the ligneous texture, and often its organic form : in its other characters it is analogous to Hornstone : it is susceptible of a fine polish.

JASPER.—In this fossil the proportion of argil to silex becomes larger, and the proportions vary much in different varieties ; so that in some there is even a transition to indurated clay : it generally also contains oxide of iron. It usually occurs in veins, and often also enters into the composition of nodules of agate. Its colours are very numerous, and generally dark : the most common are shades of red, yellow, and brown ; sometimes also it is grey or white : its lustre is weakly shining : and it is generally quite opaque, even on the edges. Its fracture is more or less perfectly conchoidal : in one variety it is earthy : it is inferior in hardness to quartz or flint, but still it is not scratched by the knife : its specific gravity is from 2.3. to 2.7. It is infusible before the blowpipe, even when the flame is excited by a stream of oxygen gas ; but in a high

heat it loses its colour. What has been named Riband Jasper, or Striped Jasper, is distinguished by its colours being arranged in stripes generally straight. The Egyptian Pebble, which occurs in nodules, and exhibits various colours or shades of the same colour, generally shades of brown, in concentric stripes or layers, is another variety of jasper.

From the variety and richness of the colours of jasper, and the high polish of which it is susceptible, it is much used for ornaments.

HELIOTROPE, or BLOODSTONE, though ranked as a distinct species, differs little from jasper. Its colour is green, which is generally marked with small crimson-red spots: its lustre is nearly resinous, and it is translucent on the edges: its fracture is imperfectly large conchoidal, and its fragments are sharp-edged. It takes a fine polish.

PITCHSTONE.—This fossil has received its name from the resemblance in lustre and texture which it frequently has to pitch. It forms entire rocks, frequently of a porphyritic structure, the pitchstone being the basis; and occurs also in veins. Its colours are green, brown, red, black, and sometimes grey: its lustre is shining, and resinous: it is translucent, at least on the edges: its fracture is imperfectly conchoidal, sometimes passing into coarse splintery: it is moderately hard; it is very brittle: its specific gravity is from 2.0 to 2.3. It is fusible before the blowpipe; by which it is at once distinguished from any varieties, either of opal or jasper, with which it has been frequently confounded. Its analysis by Klaproth gave 73 of silex, 14.5 of argil, 1 of lime, 1 of oxide of iron, 1.75 of soda, and 8.5 of water. From pitchstone, there is a

transition to what has been called Pearlstone, and from that to Pumice, both in external characters, and in composition. The Pearlstone occurs vesicular in porphyry : its lustre is shining and pearly ; its colour generally grey ; is translucent on the edges : it is soft and light : before the blowpipe it intumesces, but scarcely melts. Klaproth found it to be composed of silex 75.25, argil 12, oxide of iron 1.6, lime 5, potassa 4.5, water 4.5. Pumice likewise occurs vesicular ; is brittle, soft, and very light : its colour is grey, its lustre shining and pearly, and it is translucent on the edges. According to Klaproth, it consists of silex 77.5, argil 17.5, oxide of iron 1.75, soda and potassa 3.

OBSIDIAN is related to the immediately preceding fossils, being found both with pearlstone and pumice, and passing into them. It is of a deep black colour ; sometimes grey, or brown : its lustre is highly splendid and vitreous : it is only translucent on the edges : its fracture is large conchoidal ; its fragments sharp-edged : its specific gravity is 2.3. It melts before the blowpipe into an opaque spongy glass. According to Bergman, it is composed of 69 of silex, 22 of argil, and 9 of oxide of iron.

FELDSPAR.—This is an important fossil, from its extensive distribution, as a component part of some of the most important aggregate rocks. From the different appearances it assumes, it forms several varieties or subspecies.

Foliated or Common Feldspar occurs in various forms, massive, disseminated, and frequently crystallized : the forms of its crystals are, the flat six-sided prism, bevelled on both extremities ; the oblique four-sided prism,

also bevelled on the extremities; and the rectangular four-sided prism, acuminate by four planes. Its colours are numerous, principally red, white, grey, more rarely green: its lustre is shining and intermediate between vitreous and pearly, and is varied, according to the position with regard to incident light: it is more or less translucent; its fracture is distinctly foliated, and its fragments are rhomboidal. It is moderately hard, so as to scratch glass. Its specific gravity is from 2.2 to 2.5. It melts before the blow-pipe into a white glass. The analysis of this fossil has given very different results, and affords one of the best examples of the difficulties which still attend the determining the mineral species from chemical analysis. The following table comprises some of these discordant results:

Silex.	Argil.	Lime.	Oxide of Iron.	Barytes.	Magnesia.	
43	37.05	1.7	4	—	—	Saussure.
79	16	2.3	—	—	—	Meyer.
74	24	6	1	—	—	—
67	14	—	—	11	8	Kirwan.
70	12	—	—	8	9	Hassenfratz.
64	21	6.25	2	—	—	Chenevix.

Besides these ingredients, Vauquelin, in one variety, the Green Feldspar of Siberia, discovered potassa to the amount of 13 parts in 100, and in the adularia in nearly the same quantity.

Some of the varieties of this feldspar are liable to decomposition on exposure to the air and humidity: their lustre is diminished; their colour changed; and their

hardness and cohesion destroyed, until at length the mass passes completely into a kind of clay, which not only differs in its external characters from the feldspar, but is much less fusible. This disintegration, no doubt, arises from a chemical change, and, if an alkali enters into the composition of the feldspars, as Vauquelin's analyses appear to prove, it may perhaps arise in a great measure from the removal of this by the infiltration of water.

Foliated Feldspar enters into the composition of many of the most important aggregate rocks, and in those of every formation. Granite consists of it, intermixed with quartz and mica, and the feldspar almost always forms the principal part or basis of the granite. Gneiss is the same aggregate, having a slaty texture; and Siennite is characterised by the addition of hornblende to the other ingredients: Grunstein is an aggregate of feldspar and hornblende alone; and the name of Porphyry is appropriated to that rock where grains or crystals of feldspar are imbedded in a certain basis, as in hornstone, pitchstone, or indurated clay.

What has been described as a species, under the name of Macle or Chiastolite, is considered by Werner only as a variety of foliated feldspar. It occurs imbedded in slate, in crystals which are tetraedral prisms; and these, when viewed at their extremities, appear composed of four lines jointed at acute angles, leaving an intermediate rhomboidal empty space; hence the name of Hollow Spar which it has received.

The name of ADULARIA has been given to a variety of foliated feldspar, first discovered in the Alps, which is distinguished from the common variety by a greater degree

of lustre, which is pearly, and reflected from the internal plates, so as to give in different positions a silvery appearance, by more transparency, and rather greater hardness; its colour is greenish or yellowish white: its fracture is foliated, the cross fracture conchoidal; and its fragments rhomboidal. It occurs massive, and in crystals, of the same forms as those of the common feldspar. It melts before the blowpipe into a white glass. Vauquelin found it to be composed of silex 64, argil 20, lime 2, potassa 14. The Moonstone, as it has been termed, is an adularia.

Glassy Feldspar occurs imbedded in porphyry slate, crystallized in six-sided tables, and oblique four-sided prisms; its colour is usually grey, its lustre vitreous; it is semi-transparent; its fracture is foliated, and its fragments rhomboidal. The fossils named Meionite, and Sommite, are probably varieties of it.

LABRADORE FELDSPAR is particularly distinguished by the property of reflecting in certain positions, as the light falls upon it, very beautiful colours, particularly blue, green, and red. These are seldom reflected from the entire surface, but from spots of greater or less breadth; and the property probably arises from decomposition, and the consequent alteration of its lamellæ. Its proper colour, independent of this, is grey: its lustre is shining: it is translucent: its fracture is perfectly foliated; and, indeed, in its general characters, it bears a strict resemblance to the common feldspar. According to Kirwan, it is less fusible; yet it is melted by the blowpipe.

COMPACT FELDSPAR differs from the preceding in several characters. It has less lustre, being in general weakly shining, or glimmering: it has also less transparency,

being only translucent on the edges : its fracture is splintery, fine grained, or very imperfectly and small foliated ; and its fragments are not rhomboidal, but indeterminately angular : its hardness is also inferior. It is allied to the common feldspar, however, by its general relations, and its chemical characters, being fused like it before the blow-pipe : the one even passes into the other, and both are associated with the same fossils. It forms of itself large masses, is also a constituent of some aggregate rocks, particularly of grunstein, and occurs in imbedded crystals in the antique porphyry. Its composition has not been determined.

The fossil which the elder Saussure named Jade, and which other mineralogists considered a Hornstone, appears to be a variety of compact feldspar ; and to approach in particular in its characters to the crystallized compact feldspar, of the antique green porphyry. It has been lately analysed by the younger Saussure ; and except that it contains a larger portion of iron, it does not appear to differ much in composition from the other feldspars. Its analysis afforded silex 44, argil 30, lime 4, oxide of iron 12.5, oxide of manganese 0.05, soda 6, potash 0.25.

Even the real or oriental Jade, the NEPHRITIC STONE of mineralogists, appears to approach to this species in composition and in chemical characters. The greasy polish which this stone receives had caused it to be classed among the magnesian fossils ; but late analysis has shewn that it contains no magnesia : its composition, as determined by Saussure junior, being silex 53.75, lime 12.75, argil 1.5, oxide of iron 5, oxide of manganese 2, soda 10.75, potash 8.5, water 2.25. The nephritic stone occurs in rounded masses ; its colour is leek green, which

passes into greenish-white or light yellow; it is dull; more or less translucent; its fracture is splintery; it is hard, and difficult to break; is slightly unctuous to the touch. Before the blowpipe it melts into a white semi-transparent glass. Though not susceptible of a fine polish, so as to acquire lustre, it is much valued among the eastern nations, as from its tenacity it can be cut with great delicacy, and from its hardness is not liable to be injured.

The Bildstein of the German mineralogists appears to belong to the same species, and its characters are not very dissimilar; it occurs massive; has a splintery fracture; a greasy feel; its colour is greenish-grey, with little lustre, and from its tenacity it is applied to the same purposes as the jade, and is sometimes brought from China cut into figures, whence the name of Figure-stone given to it. This, too, was regarded as a magnesian fossil. Klaproth analysed it, and found it to contain no magnesia. Its constituent parts were silex 62, argil 24, lime 1, oxide of iron 0.5, water 10. More lately it was analysed by Vauquelin, who found it to contain potash, its ingredients being silex 56, argil 29, lime 2, iron 1, water 5, potassa 7. The alkali, Vauquelin supposes, had escaped Klaproth's notice, and he had ascribed the loss to water.

It will be observed, that all those fossils have a relation to feldspar in chemical constitution, consisting, like it, principally of silex and argil, with smaller portions of lime and iron; and approaching even nearer in the presence of an alkali, which some of the varieties of feldspar likewise contain. And as they must be removed from the

magnesian genus, where they were formerly placed, they are best connected with the species of feldspar. The Axe-stone, which has derived its name from being used by the natives of the South Sea in making hatchets, is probably a variety of the Bildstein. Its colour is green; its lustre is feebly shining; its fracture is slaty; and it is not easily broken.

The name of Andaluzite, or Hard Spar, has been given to a mineral which appears likewise to have relations to feldspar. It occurs, like it, in connection with quartz and mica, and is principally distinguished by its greater density and hardness, and its infusibility before the blowpipe. It is massive, or crystallized in rectangular four-sided prisms; is of a flesh-red colour; is translucent; is extremely hard: its specific gravity is 3.165.

ZEOLITE.—This fossil is well distinguished as a species by two chemical characters. It fuses with intumescence before the blowpipe into a white spongy glass, and it dissolves in acids, the solution being gelatinous. It has been divided into sub-species, principally from differences in the texture. The radiated is the most common: it occurs in mass, but more frequently crystallized: its crystals are rectangular four-sided prisms, acuminate on both extremities by four planes: the prism is generally broad, and sometimes so thin as to appear as a table; and frequently so aggregated, that the pyramidal terminations only are perceived. Its colour is white, with shades of grey, yellow, or red: its lustre is shining and pearly; and it is translucent, or semi-transparent. Its fracture is radiated; the rays being generally diverging, and broad or narrow: its hardness is such that it is scratch-

ed by the knife, but it scratches calcareous spar: it is brittle, and light; its specific gravity seldom exceeding 2. The narrow radiated zeolite passes into the fibrous, the fracture of which is coarse or fine fibrous, the fibres being generally divergent. This variety occurs massive, in globular pieces, and in capillary crystals: its colour is white, with various shades of red, yellow, and green: its lustre is pearly, but rather less shining than that of the radiated variety: its transparency is also less: its other characters are nearly the same. The broad radiated passes into the foliated variety, in which the fracture is perfectly foliated. It occurs under the same forms as the preceding varieties: its lustre is greater, approaching to splendid, and is pearly: its crystals are semi-transparent, and even sometimes entirely transparent. The other characters of the species apply to it. The mealy zeolite probably arises from decomposition. It occurs incrusting the other varieties; or sometimes massive; has an earthy fracture, approaching more or less to fine fibrous; is friable, dull, and opaque.

These varieties are all closely connected: they not only pass into each other in their external characters, but have the same chemical properties; and their composition is alike. They appear essentially to consist of silex and argil, with a smaller proportion of lime, and a considerable quantity of water. From the analysis of the different varieties by Vauquelin, Pelletier, and Meyer, the proportions are from 50 to 58 of silex, from 17 to 29 of argil, from 6 to 9 of lime, and from 10 to 22 of water. When acted on by acids, the lime and argil are dissolved, while the silex, in minute particles, and probably in combina-

tion with water, being diffused through the liquid, gives the gelatinous consistence. The intumescence before the blowpipe, is probably owing to the expulsion of the water from the fused matter.

CUBIZITE or ANALCIME.—This was long considered as a variety of the preceding species, and was known by the name of Cubical Zeolite. Häuy formed a distinct species of it, which he named Analcime; and Werner has also admitted it as a species, giving it the name of Cubizite. The form of its crystals is the cube, perfect, or acuminate on each angle by three planes, which sometimes are so large, that the original faces of the cube disappear. Its colour is generally white; sometimes yellowish or reddish brown: its lustre is splendid and vitreous: it is transparent, or semi-transparent: its fracture is imperfectly foliated; is harder than the zeolite, so that it scratches glass: it is also heavier; its specific gravity being 2.7. It does not form a jelly with acids.

Another fossil, which had been regarded as a zeolite, has been formed into a distinct species by Werner, under the name of Needle Stone. It occurs massive, or crystallized in rectangular four-sided acicular crystals, which are generally aggregated: its fracture is narrow and straight radiated; its colour is white; its lustre shining; it is translucent, and in the crystals transparent: it is distinguished from the radiated zeolite, by being much harder and more brittle; by its lustre being greater, and of the vitreous kind.

PREHNITE.—This fossil has some of the characters of zeolite, but is distinguished from it by being harder and heavier, and by not forming a jelly with acids. It occurs massive, and crystallized in the form of quadrangular

prisms, and of oblique four-sided or six-sided tables, often aggregated, so that the terminal planes are alone distinct. Its colour is green, of various shades, but generally light : its lustre is shining, and scarcely pearly : it is of various degrees of transparency : its fracture is foliated, or radiated : it is hard, so as to scratch glass : its specific gravity is from 2.6 to 2.9. It melts before the blowpipe with intumescence. Klaproth found it to be composed of 43.83 of silex, 30.33 of argil, 18.33 of lime, 5.66 of oxide of iron, and 1.83 of water.

The Natrolite belongs perhaps to this family. It occurs massive, and, in its fracture, presents straight or diverging fibres : its colour is light yellow, with little lustre : it is translucent on the edges, and is nearly of the hardness of prehnite. It fuses very readily before the blowpipe. What peculiarly distinguishes it in composition, is the large quantity of soda it contains, discovered by Klaproth. He found it to consist of silex 48, argil 24.25, soda 16.5, oxide of iron 1.75, and water 9 parts.

LAZULITE.—This fossil, long known by the name of Lapis Lazuli, now named also Azure Stone, is of a rich azure-blue colour, approaching sometimes to sky-blue ; with little lustre ; and only translucent on the edges. It occurs massive : its fracture is uneven or earthy : it is so hard as to scratch glass : its specific gravity is 2.7. It melts before the blowpipe into a white enamel, and, if previously calcined, is soluble in acids, forming a jelly. Klaproth found it to be composed of 46 of silex, 14.5 of argil, 28 of carbonate of lime, 6.5 of sulphate of lime, 3 of oxide of iron, and 2 of water. According to Guyton, it is not sulphuric acid that enters into its composition,

but sulphur in the state of a sulphuret of iron, and on this he supposes its colour to depend. It has been long used for ornamental purposes, particularly in mosaic work; and its powder furnishes the fine paint known by the name of Ultramarine. It is found in Persia, China, and other countries of Asia.

The name of AZURITE is given to a fossil, which, like the preceding one, is of a blue colour, generally a light indigo-blue. It occurs disseminated, and in small imbedded crystals. It has a foliated fracture, and is softer than lapis lazuli. It loses its colour before the flame of the blowpipe, but does not melt. Klaproth found it to consist of silex, argil, and oxide of iron.

STAUROLITE or CROSS STONE.—This fossil derives its name from occurring in twin crystals, (rectangular four-sided prisms acuminate by four planes), which intersect each other by the broad faces of the prism, so that the planes of the acumination coincide two and two, and the double crystal has the appearance of a cross. It occurs also, however, in single crystals of the same form. Its colour is white: its lustre shining and vitreous: it is translucent, or semi-transparent. Its fracture is foliated: it is hard, so as to scratch glass easily: its specific gravity is 2.3. It melts before the blowpipe, and is phosphorescent when thrown on burning fuel. According to Klaproth's analysis, it consists of 40 of silex, 16 of argil, 18 of barytes, and 15 of water.

GARNET.—With this fossil, a new family, very different in their characters from the zeolite and the fossils allied with it, commences. The garnet occurs both massive and crystallized: the forms of its crystals are, the dodecaedron, with rhomboidal planes, either perfect, or

truncated on all its edges giving 36 faces, of which 12 are rhombs, and 24 elongated hexagons. By the enlargement of these truncations, so that the planes of the dodecaedron disappear, a short double eight-sided pyramid is produced, each of the summits of which is acuminated by four planes; and this last form is sometimes modified, by truncation of its angles. The variety which is named the precious garnet is almost always crystallized; the common is often massive, but also crystallized under the same forms. The former is of a red colour, of various shades, and with intermixture of other colours, generally dark: the lustre is more or less shining, and is vitreous: it varies in transparency, from completely transparent to translucent: its fracture is more or less perfectly conchoidal: it is harder than quartz, so as to scratch it: its specific gravity is from 4 to 4.3: it is therefore one of the heaviest of the earthy fossils. The common garnet differs from the precious, in its colours, which are usually brown or green, having frequently, however, shades of red; in having less lustre and transparency; in its fracture, which is uneven; and in being inferior in hardness and specific gravity, the latter rarely exceeding 3.75. Both varieties are melted before the blowpipe; the common garnet with most facility. The results of the analysis of both vary considerably. The three following, the first and second by Klaproth, the third by Vauquelin, apply to the precious garnet:

Silex.	Argil.	Lime.	Magnesia.	Oxide of Iron.	Oxide of Manganese.
35.75	27.25	—	—	36	.25
40	28.5	3.5	10	16.5	.25
36	22	3	—	41	—

The garnet is in use as a gem, though it is one of inferior value.

The Pyrope is what was formerly named the Bohemian Garnet, and though arranged as a species, appears to be merely a variety of garnet, from which it differs only in being perfectly transparent, in its colour being dark-blood-red, and its occurring not crystallized, but in imbedded grains. The second analysis in the above table applies to it.

The Melanite, as it is now termed, was known by the name of Black Garnet, from its colour, which is velvet-black. It is crystallized in the form of a six-sided prism, acuminate by three planes, and the edges truncated: its lustre is shining: it is opaque: its fracture is imperfectly conchoidal: its specific gravity 3.8. According to Vauquelin, it is composed of silex 35, argil 6, lime 32, oxides of iron and manganese 25.

GRENATITE, the Staurotide of Häuy, occurs crystallized, in the form of a broad six-sided prism, sometimes bevelled; the crystals are small, of a dark-reddish brown colour, having a lustre between vitreous and resinous, opaque, or sometimes translucent, hard and brittle. It consists of silex 33, argil 44, lime 3.8, oxide of iron 13, oxide of manganese 1.

LEUCITE.—This fossil, which occurs in lava, was, from the appearance of its crystallization, named White Garnet; but it differs in its general characters from garnet, and was therefore constituted a species by Werner, under the name of Leucite. The form of its crystals is the double eight-sided pyramid, the summit of each pyramid being acuminate by four planes, so as to produce a crystal

with 24 sides. Its colour is white, with a yellowish or greyish tinge: its internal lustre is shining, and somewhat vitreous: the crystals vary from opaque to transparent: its fracture is foliated, or imperfectly conchoidal: its specific gravity is 2.4. It is not fused before the blowpipe. It is the first mineral in which the existence of potassa was discovered in any considerable quantity,—a discovery due to Klaproth. From his analysis, which is confirmed by Vauquelin, it is composed of 54 of silex, 24 of argil, 21 potassa, and, according to Vauquelin, 2 of lime.

VESUVIAN.—This name has been given to a fossil found in the stony masses ejected from Vesuvius. It is crystallized in rectangular four-sided prisms, more or less deeply truncated on all its edges. Its colour is olive-green, passing sometimes into yellow, or brown; its external lustre is splendid and vitreous: it is translucent: its fracture is small-grained uneven: it is harder than quartz: its specific gravity is from 3.3 to 3.5. It melts before the blowpipe into a yellowish glass. According to Klaproth, it consists of silex 35.5, lime 33, argil 22.25, oxide of iron 7.5, oxide of manganese 6.25. It is sometimes cut as a gem.

OLIVIN.—This fossil occurs in grains or rounded pieces, or sometimes, though rarely, crystallized in rectangular four-sided prisms. Its colour is green, of different shades: its lustre is shining and vitreous: it is semi-transparent: its fracture is small conchoidal: it is inferior in hardness to quartz: its specific gravity is 3.2. It can scarcely be melted by the blowpipe, without addition: in nitric acid it loses its colour, becoming of a pale green. It consists, according to Klaproth's analysis, of

silex from 48 to 50, of magnesia from 37 to 38, lime 0.25, oxide of iron 12.5. It is found generally imbedded in basalt, and sometimes in the rocky fragments ejected by volcanoes. With this fossil, the CHRYSOLITE has been united by Haiüy: in composition they are nearly the same; Klaproth having found the chrysolite to be composed of 38 of silex, 39.5 of magnesia, and 19 of oxide of iron: in colour, lustre, hardness, fracture, and forms of crystallization, they are also similar; or the differences are so slight, as perhaps are scarcely sufficient to establish a specific distinction. It occurs in grains, or crystallized in rectangular four-sided prisms, truncated or bevelled on the lateral edges, and acuminated by six or eight planes. Its colours are various shades of green; its lustre is resplendent and vitreous: it is transparent: its fracture is perfectly conchoidal: it is not very hard, as it can be scratched by quartz: it is brittle: its specific gravity is 3.4. It is infusible before the blowpipe, but melts with borax, forming a transparent greenish glass.

The fossil named AUGITE has also considerable resemblances to the olivin, and is frequently found with it, both in basalt and in volcanic fossils. It differs in the form of its crystals, which is a rectangular six-sided prism bevelled on the extremities; in its colour being a darker green, approaching to black; in being harder and heavier; the specific gravity being from 3.4 to 3.7: its lustre is shining and resinous: it is translucent, or faintly transparent: its fracture is uneven. It fuses with difficulty before the blowpipe, in which character it approaches to the olivin, as it does in composition; the augite, according to Vauquelin, being composed of 52 of

silex, 13.2 of lime, 3.33 of argil, 10 of magnesia, 14.66 of oxide of iron, and 2 of oxide of manganese. They perhaps, therefore, may be regarded as forming only one species.

The species which has been named COCCOOLITE, has relations to these fossils. It occurs massive, in large and small granular distinct concretions, is of a green colour, with considerable lustre, and translucent; is hard, and has a foliated fracture. It consists, according to Abilgaard's analysis, of silex 42, argil 15, lime 13, oxide of iron 8, oxide of manganese 14, water 3 parts.

THUMERSTONE, or VIOLET SCHORL, as it has been named, occurs generally crystallized in very flat and oblique rhombs. Its colour is clove-brown, which passes into violet, or into grey: its external lustre is splendid; and it varies from transparent to translucent: its fracture is uneven, or imperfectly conchoidal: it is nearly of the hardness of quartz: its specific gravity is 3.2. It melts before the blowpipe, into a semi-transparent greenish glass. According to Vauquelin, it consists of 44 of silex, 18 of argil, 19 of lime, 14 of oxide of iron, 4 of oxide of manganese.

SCHORL is a fossil which occurs frequently in primitive rocks, especially in granite, and sometimes in quartz. It is of a black colour; with a lustre which is weakly shining, and is generally opaque, or slightly translucent on the edges. It occurs massive, and frequently crystallized; the form of its crystals being a three-sided prism, the lateral edges of which are cylindrically convex, acuminate at the extremities by three planes, and generally acicular: its fracture is imperfectly conchoidal, or uneven: its

hardness is a little inferior to that of quartz : its specific gravity is 3. It melts with ebullition before the blow-pipe into a greyish slag. It is distinguished by becoming electric by heat, presenting at one extremity positive electricity, at the other negative. From an analysis of it by Wiegleb, it appears to be composed of 33.33 of silex, 40.83 of argil, 20.41 of iron, and 3.33 of manganese.

The Tourmalin is very nearly allied to schorl, and is chiefly distinguished from it by its colours, which are brown, green, red, and blue, of numerous shades, generally dark, and by its greater lustre. Its forms of crystallization are similar ; the crystals vary in transparency from nearly opaque to perfectly transparent : they are often opaque in the thickness of the prism, but transparent more or less in its length : its fracture is conchoidal : it is harder than quartz : its specific gravity is from 3.0 to 3.6. It is rendered electrical like the schorl by a moderate heat : before the blowpipe it fuses into a grey enamel. It consists, according to Vauquelin, of 40 of silex, 39 of argil, 3.84 of lime, 12.5 of oxide of iron, and 2 of oxide of manganese. Some varieties are beautiful from the richness of their colours, and their lustre, and are cut as gems.

PISTACITE, the Epidote of Haüy, the Thallite, Acanthicone, or Arandalite of other mineralogists, has been ranked as a variety of common actynolite ; but there is every reason to regard it as a different species. According to the analysis of it by Descostils, it consists of silex 37, argil 27, lime 14, oxide of iron 17, oxide of manganese 1.5 ; according to that of Vauquelin, of silex 37, argil 21, lime 15, oxide of iron 24, oxide of manganese 1.5. If these analyses be compared with those of the

schorl and tourmalin, it will appear that they are the same in ingredients, and do not differ greatly in proportions; and the external characters of this fossil allow it to be classed with them. It is usually crystallized in six-sided, or oblique four-sided prisms: is of a pistachio-green colour: the lustre is shining and vitreous; the crystals are more or less transparent; the fracture is foliated or radiated: it is hard and brittle.

SCHORLITE, having a considerable resemblance to Schorl, was regarded as a variety of it, and named from its colour, White Schorl. Werner, supposing it to be nearly allied to beryl, connected it with it, and named it Schorlous Beryl. He has since, however, considered it as a distinct species. It is usually of a light yellow colour, which passes into deep yellow, green, or greenish-white, and also violet blue and red. It occurs massive, or crystallized in long hexaedral prisms, more or less translucent, and having a shining lustre; its cross fracture is foliated; it is moderately hard and brittle. It consists, according to Klaproth, of 50 of argil, and 50 of silex; according to Vauquelin, of argil 52.6, silex 36.8, lime 33, and water 1.5.

Besides the preceding siliceous fossils, silex is likewise found deposited in a stalactitic form from waters, in which it has been previously in a state of solution. The deposit from the Geyser fountain is the principal example of this kind. It occurs in massive pieces; the surface sometimes botryoidal: its fracture is either compact or fibrous; it has scarcely any lustre; is of a greyish-white colour; and is only semi-indurated, so as to be

easily broken. It consists according to Klaproth's analysis, of 98 of silex, 1.5 of argil, 0.5 of oxide of iron.

Similar deposits are formed from some other mineral springs: the Fiorite, found in Tuscany, is of this kind. In some siliceous stalactites, the surface is even covered with crystals of quartz.

SECT. VIII.

OF ZIRCON FOSSILS.

To the zircon genus of fossils belong the two fossils in which this earth is found, the Zircon and the Hyacinth. And to these Werner has added another species, from its external characters, the Cinnamon Stone, which has not been analysed.

The ZIRCON or JARGON occurs in rounded or angular grains, and crystallized; its crystals being rectangular tetraedral prisms acuminated by four planes, with the lateral edges truncated, or the angles bevelled; or octaedrons, perfect or truncated on the angles. Its principal colour is grey, but it has also often shades of green, blue, yellow, and brown; its internal lustre is resplendent and adamantine; it is transparent; its fracture is small conchoidal; it is extremely hard, so as to be scarcely affected by the file: its specific gravity is 4.6 or 4.7. It does not melt alone before the flame of the blowpipe, but if borax is added, it forms a transparent glass. According to Klaproth's analysis of it, it consists of zircon 68, silex 31.5, oxide of iron 0.5. It is cut as a gem, and is some-

times sold for the diamond, as, when cut, it has a similar play of colours.

The HYACINTH occurs in grains, or crystallized: the form of its crystals being the rectangular tetraedral prism acuminated by four planes, the dodecaedron, or octaedron; its principal colour is what has been named Hyacinth Red, but often with various other shades: its lustre is resplendent and resinous: it is transparent, or semi-transparent: its fracture is perfectly straight foliated: it is very hard, scratching quartz: its specific gravity is 4.6. It loses its colour before the flame of the blowpipe, but is not fused. It melts with borax into a transparent glass. According to Klaproth's analysis of the hyacinth of Ceylon, it consists of zircon 70, silex 25, oxide of iron 0.5, with 4.5 of loss: according to Vauquelin's of the hyacinth of Expailly, it contains zircon from 64 to 66, silex 32 or 31, oxide of iron 2, with a loss of 1.5.

CINNAMON STONE occurs in fragments of a yellowish-brown colour, internally shining, its lustre being intermediate between resinous and vitreous; it varies from transparent to translucent; is hard, and has an imperfect conchoidal fracture. It is brought from Ceylon.

SECT. IX.

GADOLINITE.

THIS forms the only known species of the genus of which the newly discovered earth Ittria is the base, for although this earth has been found in the Ytthro-tantalite, yet this contains it only in small quantity, and is rather a

metallic fossil, belonging to the genus tantalum. The gadolinite occurs massive and disseminated : its colour is deep black : its internal lustre is resplendent : it is opaque, or feebly translucent : its fracture is conchoidal : its hardness is such that it is not scratched by the knife : its specific gravity is 4.2. It intumesces before the blow-pipe, but is not fused. With nitric acid it forms a gelatinous solution. According to Klaproth, it consists of ittria 59.75, silex 21.25, oxide of iron 17.5, argil 0.5, water 0.5. The analyses of it by Ekeberg and Vauquelin give the proportion of ittria rather less, and of silex and iron somewhat greater.

CHAP. III.

OF METALLIC MINERALS.

THE Metals occur in nature either in a pure form, or combined with certain substances, by which they are said to be mineralized ; the name of Ore being given to those compounds in which they exist in this mineralized state. Each metal, in a system of Chemical Mineralogy, forms a genus, under which are comprised the natural substances of which it is the chief constituent part. These, like the earthy fossils, are connected entirely by their chemical relations ; the different ores of one

metal having in general no common external characters, but presenting the utmost diversity; and being therefore altogether incapable of being associated by any other arrangement than that founded on their chemical constitution.

Several of the metals, especially of those newly discovered, existing in sparing quantity in nature, and in combination with some others, afford, properly speaking, no mineral species. This is the case with palladium, iridium, rhodium, and osmium; they are merely associated with native platina, and of course their mineralogical history is connected with that of this metal.

Metallic minerals in general, though not without many exceptions, retain the characteristic metallic properties. They have a considerable gravity, have often the metallic lustre, are destitute of transparency, and are of dark colours. These characters in particular belong to many of the native metallic oxides and sulphurets, but are less observable in the saline combinations of this order.

SECT. I.

OF NATIVE GOLD.

THIS is the only species that can be considered as belonging to this genus, gold not occurring in a mineralized state. Native gold is either pure, or alloyed with portions of other metals, more particularly with silver, copper, and tellurium. Its colour is yellow, approaching to that of pure gold, according as it is more free from other

metals. Its lustre is metallic and shining : it is soft, highly malleable, and ductile : its fracture is hackly ; and its fragments indeterminately angular : its specific gravity is always above 12, and rarely equal to 19. The forms under which it exists are various. It occurs sometimes, though rarely, crystallized ; the forms of the crystals being the cube, the octaedron, and the dodecaedron with rhomboidal planes : they are generally minute and imperfect. It is also found capillary, filiform, in thin plates or spangles, and sometimes massive : sometimes also in small grains in the sand of rivers and streams, forming what is named Gold Dust. There are, besides this, which is the most common variety of native gold, two sub-species, described by Werner, one of a brass yellow colour, generally disseminated, or in small plates, in which the gold appears to be alloyed with silver and a little iron ;—the other of a steel-grey colour, passing to yellow, in which the proportion of alloy is probably greater. Native gold is soluble only in nitro-muriatic acid, by which it is distinguished from every metal or metallic combination except platina ; and from this it is easily discriminated, not only by external characters, but by its solution being precipitated by sulphate of iron, which throws down the gold in a metallic state.

Native gold occurs most commonly with quartz, sometimes with feldspar, calcareous spar, and sulphate of barytes : generally in primitive mountains in veins ; sometimes also disseminated in the rock itself : it is also found, however, in alluvial soil, derived, no doubt, from the disintegration of the rock in which it had existed ; and such also must be the origin of that found in the sand of ri-

vers. The countries where it exists in largest quantity are Mexico and Peru, Siberia, Hungary, and Transylvania; though it is very extensively diffused in more sparing quantities. In Africa, though mines of it have not been explored, it appears to be abundant, as the sand of many of the rivers is richly auriferous. In [a valley in the county of Wicklow in Ireland, it has been found in considerable quantity under the soil, and in a stream which runs over rocks of argillaceous slate penetrated with veins of quartz; but the vein in which it must have existed has not been discovered *. In Scotland, particularly at Leadhills, it is sometimes found disseminated in quartz, and may be collected in small quantity from the neighbouring alluvial soil.

There are some other minerals which contain gold in such quantity, that they are explored and wrought to extract it, and they have hence been regarded as gold ores: they are not strictly so, however, as they contain larger quantities of other metals, and the gold only in inferior proportion. The principal of these are the two native alloys of a metal named Tellurium, the graphic gold ore, or graphic sylvanite, and the white sylvanite, which pass into each other. The alloy consists of from 20 to 27 of gold, with from 45 to 60 of tellurium, 10 of silver, and sometimes a little lead. It is in minute indeterminate crystals of a greyish-white colour, which are generally attached to each other laterally, and dispersed on the surface of the matrix, so as to bear some resemblance to

* Nicholson's Journal, 4to, vol. ii. p. 223.

printed letters ; hence the name, graphic gold ore. It is found in Transylvania.

Gold is also found in still smaller quantity in some other ores, especially in some varieties of sulphuret of iron, or pyrites, which are hence named Auriferous, as well as in some of the other native sulphurets, as those of quicksilver, zinc, and lead. In these it has been supposed by many mineralogists not to be in a combined state, but disseminated, as it can sometimes be discerned by the eye, or the microscope ; and if extracted by boiling the ore in nitric acid, it is found in grains. On this subject, however, whether gold is ever truly mineralized or not, there is still some doubt. Some of these ores are sufficiently rich to be wrought as gold ores.

SECT. II.

OF NATIVE PLATINA.

PLATINA, like gold, is found only native. Of its natural history, the accounts which we have are still defective. It has not been found in the original repository, but in the sand of certain streams, mixed with particles of magnetic iron-ore, gold, copper, and iron pyrites, crystals of quartz, hyacinth, and occasionally other substances. It is found in Peru, and in New Grenada, in South America. Vauquelin has more lately discovered it in the ores of the mines of Guadalcanal, in Estremadura. It appears to exist in the metallic state in these ores, which consist chiefly of copper, with silver ; and, what

is rather singular, none of the four newly discovered metals, which are contained in the Peruvian platina, are found in that from Spain *. In a specimen of native platina from Brazil, Dr Wollaston has found palladium, and some traces of iridium. It is probably, therefore, similar to that from Peru.

Native platina is in the form of grains, which, in the state in which it is imported into Europe, are seldom angular, but flattened : pieces have, however, been found of a greater size, as that of a pigeon's egg. Its colour is white, approaching to a light steel-grey ; its lustre metallic and shining. It is semi-hard, perfectly malleable, flexible, and has a specific gravity above 15. It is the least fusible of the native metals, not melting except in an intense heat, such as that excited by a powerful burning mirror. It is soluble only in the nitro-muriatic acid ; and its solution in that acid gives a yellow or reddish precipitate on the addition of muriate of ammonia.

SECT. III.

OF ORES OF SILVER.

SILVER is found in nature in its metallic state, either pure, or alloyed with other metals. It also occurs mineralized, and there are several well-marked species of its ores. In either state it is found in largest quantities in Mexico, Peru, and other provinces of South America.

* Nicholson's Journal, vol. xvii. p. 129.

It is also met with in some of the countries of Europe, and in Siberia. America furnishes, however, nearly all the silver of commerce.

Native silver has the general qualities of the metal. Its colour is white, though frequently tarnished : its lustre metallic ; and it gives a shining streak : it is perfectly malleable and ductile, usually flexible : it is soft : its fracture is hackly. The specific gravity of the pure metal is 10.5, but in the native state is somewhat varied according to the quantity of alloy. Native silver occurs massive, branched, capillary, in thin plates, and crystallized ; the forms of its crystals being the cube, the octaedron, the rectangular six-sided prism, the six-sided pyramid, and the double six and three-sided pyramid. These crystals are generally small and aggregated. Masses of native silver have sometimes been discovered of great size : one is said to have been found in the mines of Saxony in 1478, of 400 weight.

A sub-species of native silver is marked by Werner, in which the colour is more or less yellow, and its specific gravity greater than that of common native silver, from an alloy of gold.

By an alloy of antimony with silver, characters are acquired sufficiently distinctive to form a species, which has been named Antimonial Silver. It differs from the preceding in having less external lustre, though internally it is highly shining, and externally acquires more lustre in the streak, in its colour being tin-white, its fracture being lamellated, and in being brittle. It is soft : its specific gravity is from 9.4 to 10. It occurs massive, disseminated, and crystallized ; the forms of its crystals being

the prism of four or six sides, the table of six sides, and the cube. It is melted before the blowpipe, and is covered with a white powder when immersed in nitric acid. According to Klaproth's analysis, it consists of from 67 to 84 of silver, with from 24 to 16 of antimony; according to Vauquelin's, of 78 of silver, and 22 of antimony.

Another native alloy of silver, forming a species, is that with arsenic, containing also sometimes iron and antimony, named Arsenical Silver. Its colour is tin-white, which is, however, always tarnished, and often approaching to grey. Its external lustre is weakly shining; internal highly so, and metallic, being increased by the streak; its fracture is foliated; it is soft and brittle. It occurs massive, disseminated, and crystallized; the forms of its crystals being the six-sided prism or pyramid. Before the blowpipe it exhales fumes of arsenic and antimony, the former being distinguished by their garlic odour. According to its analysis by Klaproth, it consists of 35 arsenic, 44.25 iron, 12.75 silver, and 7 of antimony. Both it and the antimonial silver, which are closely related, are rare minerals. They are found principally in the Hartz.

Silver mineralized by sulphur, forms a well-known ore, the Vitreous Silver Ore, or Silver Glance: Sulphuretted Silver. Its colour is lead-grey, passing to steel-grey, and sometimes darker; its lustre is shining, or glistening, and metallic; its fracture is uneven, sometimes inclining to conchoidal; it is soft, so as to be cut by the knife; malleable and flexible; its specific gravity is about 7.200. It occurs massive, disseminated, of various imitative shapes, as filiform, &c. and crystallized, the forms of the crystals being the cube, or the octaedron, and more

rarely the dodecaedron, and the double eight-sided pyramid; the crystals are generally small, and superimposed. Before the blowpipe its sulphur exhales, and a globule of silver is obtained. It consists, according to Klaproth, of about 84 of silver, with 16 of sulphur. It is one of the most abundant of the silver ores. What has been named Brittle Vitreous Silver Ore, and which differs from the former principally in its brittleness, and in the forms of its crystals, which are prisms and tables, might perhaps be regarded as a variety of the sulphuretted silver, though, from Klaproth's analysis, which proves it to contain, in 100 parts, 10 of antimony, and 5 of iron, it is perhaps rather chemically connected with the next species, the red silver ore.

The name of Red Silver Ore has been given to a species, which, from its composition, may be named Sulphuretted Antimonial Silver. Its colour is red, of various shades, passing sometimes into grey or iron black, giving rise to two varieties, the light red and dark red ores; its lustre is shining, and metallic or adamantine: its streak is always red, as is also its powder: when massive, it is opaque or nearly so; when crystallized, transparent, or semi-transparent: its fracture is uneven, passing into imperfect conchoidal, or foliated: is soft and brittle: has a specific gravity from 5.56 to 5.59. It occurs massive, disseminated, dendritic, and crystallized; its crystallizations being the six-sided prism, and the six-sided pyramid, modified by various acuminations and bevellements. The crystals are generally small. Heated on charcoal by the blowpipe, it decrepitates, melts, exhales a white vapour having an unpleasant odour, and

gives a globule of silver. The analysis of this ore is stated in a different manner, though the ultimate elements are the same, by Klaproth and Vauquelin. According to the former, it consists of silver 62, antimony 18.5, sulphur 11, sulphuric acid 8.5 : According to the latter, of silver 56.67, antimony 16.13, sulphur 15.07, and oxygen 12.13 ; this oxygen, as he supposes, being divided between the metals, forming oxides, with which the sulphur is combined. This opinion is more probable, than that it should be united with the sulphur to form sulphuric acid, as no acid appears ever to be combined directly with metals without the medium of oxygen, and as, on the other hand, sulphur often exerts affinities to metallic oxides.

A species has been described by mineralogists, under the name of Black or Sooty Silver Ore, which occurs as a coating of other silver ores, sometimes in separate masses, corroded and friable, or in geodes of other ores, with little lustre, and of a bluish black colour ; its fracture when solid being earthy. It has been generally regarded as produced by alteration of some of the other silver ores, either vitreous silver ore, or the red silver ore, with which it is often associated, and into which it appears to pass. Werner, however, considers it as an original deposition.

Grey Silver Ore, as it has been named, cannot properly be regarded as an ore of silver, since, according to Klaproth's analysis, it contains not more than from 9 to 20 parts of silver in 100 parts, while it contains from 40 to 48 of lead, and from 8 to 21 of antimony. It consists besides of from 12 to 22 of sulphur, 1 or 2 of iron ; from 1 to 7 of argil, and a minute trace of silex. There

are two varieties of it, the light grey or white silver ore, the colour of which is a light lead grey; its lustre is shining and metallic; its fracture is even; it is soft and brittle; occurs always massive or disseminated: and the dark-grey silver ore, the colour of which is iron grey, passing to black, without lustre; its fracture is earthy; it is brittle and soft. They pass into each other, and into the other native metallic sulphurets.

Silver mineralized by muriatic acid, forms a well-defined species, to which, according to the old chemical nomenclature, the name of Horn Silver Ore has been given. Its colour is pearl-grey, of various shades, and passing into white or blue, sometimes into green: externally, its lustre is shining: internally, it is somewhat more dull, and appears resinous: it is more or less translucent; gives a shining streak; is soft, so as to be easily cut; is also malleable: its fracture is fine grained uneven; specific gravity about 4.7. It occurs rarely massive; more frequently crystallized: its crystals being acicular, or cubes, which are aggregated, imbedded, or superimposed. Heated before the blowpipe on charcoal, it melts very easily, exhales a disagreeable odour, and gives a globule of silver. Another characteristic chemical character of it is, that when breathed on, and rubbed by a piece of iron or zinc, the rubbed surface exhibits a thin film of reduced silver. According to Klaproth's analysis, it consists of silver 67.75, muriatic acid 21, sulphuric acid 0.25, oxide of iron 6, argil 1.75, lime 0.25. Woulfe found a larger proportion of sulphuric acid.

These are the proper silver ores. This metal is likewise often present in small quantity in other metallic

ores; from which, from its commercial value, it is an object to extract it, and hence these have been also placed, but improperly, under this genus.

SECT. IV.

OF ORES OF QUICKSILVER.

THIS metal occurs native and mineralized. Its most abundant mines are those of Idria, Carinthia, the Palatinate, and the Dutchy of Deux Ponts, and of Almaden in Spain, the last of which have been worked more than two thousand years. It is also found in some other countries in Europe, as in Hungary, Bohemia, and Transylvania; likewise in Siberia, and in Peru.

Native Quicksilver is found in globules, on the surface, or in the crevices of other mercurial ores, or other fossils, retaining the lustre, opacity, mobility, and other properties of the pure metal.

It occurs also alloyed with silver, forming a species, of which, from the various proportions of silver, there are two varieties, that in which the amalgam is soft, and that in which, from the larger proportion of silver, it is firm or solid. Its colour is white, approaching more or less to that of silver; its lustre metallic: when firm, it is brittle; and it is extremely heavy. It is found generally disseminated or superficial; sometimes in crystals which are small, and generally not well determined, but which appear to be octaedrons or dodecaedrons. Exposed to the heat of the blowpipe, the quicksilver is volatilized, and

the silver remains. It is also recognised by giving to copper or gold a white colour when rubbed on its surface. The quicksilver is always in largest proportion, amounting to from 64 to 74 in 100.

Quicksilver has been supposed to occur in nature in the state of a pure oxide; but this is not admitted by Werner.

The oxide combined with muriatic, and a portion of sulphuric acid, forms the species which has been named, according to the old chemical language, Mercurial Horn Ore. This is generally found in small crystals in the cavities of an indurated clay: their form, from their smallness, is not easily determined, but appears to be that of the four-sided prism acuminated by four planes. Its colour is grey, of various shades, with a pearly lustre. It is faintly translucent: its fracture is foliated: it is soft and brittle, so as to be easily scraped, or cut with a knife. Before the blowpipe it is volatilized entirely. Lime-water added to it produces an orange colour. It was discovered by Woulfe in the mines of the Palatinate. He recognised in it sulphuric, as well as muriatic acid; but its analysis does not appear to have been very accurately performed.

Quicksilver is mineralized by sulphur, and this forms its most abundant ore, to which the name of Cinnabar has been given. Its colour is red, of various shades; its lustre also various, passing from shining to dull. It occurs massive, disseminated, and crystallized, the crystals being generally six-sided tables, six-sided prisms, three-sided pyramids, or octaedrons, and being always small. When crystallized, it is sometimes translucent or semi-

transparent ; when massive, it is always opaque. It is brittle and soft ; the fracture is foliated, uneven, sometimes even and conchoidal, or earthy. Its specific gravity varies much, being from 6 to 10. Heated by the blowpipe, it is volatilized, with smoke, a blue flame, and an odour of sulphur. Its composition is various from intermixture. According to Born, pure cinnabar consists of 80 parts of quicksilver and 20 of sulphur. The ore has been lately analysed by Klaproth : a specimen from Japan, the foreign substances mixed with it having been removed, gave 84.5 of quicksilver, and 14.75 of sulphur ; one from Carniola gave 85, and 14.25.

Hepatic Quicksilver Ore occurs massive. Its colour is intermediate between dark-red and lead-grey, or iron-black. It has little lustre, and is perfectly opaque. Its fracture is even, or slaty. It is soft, brittle, and has a specific gravity of from 7 to 9. It is the most abundant ore in the mines of Idria. The nature of it was not well ascertained, but it has lately been examined by Klaproth, who has given the following as the results of the analysis: Quicksilver 81.8, sulphur 13.7, charcoal 2.3, silex 0.65, argil 0.55, oxide of copper 0.2, water and loss 0.7. It appears, therefore, to be merely cinnabar, altered by the intermixture of small quantities of foreign substances.

Mercury is easily extracted. The ore from which by far the greater part of what is used is obtained, is the sulphuret. The mercury is separated by distillation ; quantities of lime, and sometimes of iron, being added to combine with the sulphur. When native, it is separated by agitation with water, which suspends the earthy matter, and allows the liquid mercury to subside.

SECT. V.

OF ORES OF COPPER.

COPPER occurs native, and likewise mineralized, forming a very extensive family of ores, the species of which are in general well defined. They are found more or less in almost every country ; and being in general easily worked, copper is one of the metals of earliest discovery, and which has been most extensively used.

Native Copper possesses the general properties of the pure metal. Its colour is red, but frequently tarnished : its lustre metallic, and it gives a shining streak : it is flexible, and ductile, and malleable : its fracture, like that of other metals, is hackly. Its specific gravity is from 7.6 to 8.5. It occurs massive, more frequently in branched pieces, dendritic, in thin plates, or crystallized ; its crystals being the cube, the octaedron, the dodecaedron, the triaedral and hexaedral pyramid, the hexaedral and tetraedral prism, variously modified, and generally very small and aggregated. Though frequently occurring in copper mines, it is seldom in such quantity as to render its extraction an object of importance.

Copper is found mineralized by oxygen, forming what has been named by mineralogists Red Copper Ore, and of which there are several varieties, comprised under the florid red copper ore, and the brick-red copper ore. The colour of the former is cochineal-red of various shades, approaching sometimes to carmine-red : its lustre is semi-

metallic, or adamantine : it is opaque, when massive ; transparent, or semi-transparent, when crystallized : it is semi-hard ; brittle : its specific gravity is about 3.9. Its fracture is compact, or foliated, or fibrous ; whence different varieties are formed. The compact is always amorphous, and occurs massive, in plates, and disseminated : the foliated occurs in these states, and likewise in crystals, the forms of which are the cube and octaedron, perfect or truncated on the edges or angles : the fibrous is generally in capillary crystals. The florid red copper ore appears to be a pure oxide of copper : it is reduced when heated by the blowpipe on charcoal : it is soluble in muriatic acid without effervescence : it also dissolves in nitric acid, but an effervescence attends the solution from the disengagement of nitrous gas. By Mr Chenevix's analysis, it consists of about 88.5 of copper, and 11.5 of oxygen. The brick-red or tile-red copper ore, is regarded as a mixture of oxide of copper and oxide of iron. It occurs earthy or indurated, of a red colour, inclining to yellow or brown, destitute of lustre or transparency, and is found either as an incrustation of other copper ores, or disseminated or massive. It is not easily reduced, but becomes black when heated by the blowpipe. It effervesces with nitric acid, forming a green solution, from which ammonia throws down a yellow or brown precipitate, which becomes blue. The quantity of oxide of copper it contains is various ; the copper extracted from it amounting from 10 to 50 parts in 100. Hence it is to be regarded, not as a proper species, but as a mechanical mixture of numerous gradations. By the

large intermixture of oxide of iron, it forms what has been named Iron-shot mountain green.

Oxide of copper combined with carbonic acid, has been divided by Haüy into two natural species, the Blue Carbonate, and the Green Carbonate; the differences between which are perhaps sufficiently important to be regarded as specific, arising probably from different states of oxidizement of the metal, or perhaps in part, as some have imagined, from the combination of water.

The blue carbonate has been known under the name of Mountain Blue. It is generally of a deep blue colour: one variety is earthy, usually forming an incrustation, sometimes disseminated or massive, the colour of which is smalt blue without any lustre. The other is indurated: its principal colour is azure-blue: when crystallized, its lustre is shining and glassy: when massive, it is dull; the latter is opaque, while the crystals are translucent, or semi-transparent. It is soft and brittle: the fracture is striated, sometimes straight, sometimes divergent. It occurs massive, disseminated, incrusting, botryoidal, and often crystallized; its forms being the rectangular, and the rhomboidal four-sided prism, acuminate by four planes. These crystals are small and aggregated.

This species dissolves in nitrous acid with effervescence. Analysed by Pelletier, its constituent parts were from 66 to 70 of copper, from eight to ten of oxygen, from 18 to 20 of carbonic acid, and 2 of water.

The green carbonate of copper comprises two varieties, what have been named Mountain Green, and Malachite. The first is sometimes massive, but more generally forms

an incrustation : its colour is verdegris-green : it is generally dull : its internal lustre, however, is sometimes shining and resinous ; and it varies from translucent, or even semi-transparent, to opaque : its fracture is earthy or small conchoidal : it is soft and brittle : it becomes black when heated before the blowpipe ; communicates, like other carbonates of copper, a green colour to borax, and effervesces, though slightly, with acids, being at the same time dissolved. It appears to consist of oxide, or rather carbonate of copper, with argil and lime.

The other variety, or Malachite, is also subdivided, according to its fracture, into compact and striated, the second being the more common. The colour of both is emerald green, passing into other varieties of green : their lustre is silky or pearly. The fibrous occurs massive, disseminated, incrusting, and crystallized in capillary, and acicular prismatic crystals, which are translucent, while, when massive, it is nearly opaque ; the striæ exhibited by its fracture are generally divergent, and pass from delicate fibrous to narrow striated. The compact occurs massive, disseminated, botryoidal, and of other imitative forms, and crystallized in rectangular four-sided prisms, acuminate by four planes. It is opaque or faintly translucent : its surface is generally striped or zoned : its fracture passes from small conchoidal, or even, to very delicate fibrous : it is rather harder than the other variety, but is easily scratched by the knife. Both have a specific gravity about 3.5, or varying to 3.9. They decrepitate, and become black when urged by the flame of the blowpipe ; give a green colour to borax, and effervesce with acids. The fibrous malachite analysed by Klaproth

was found to consist of 58 of copper, 18 of oxygen, 12.5 of carbonic acid, and 11.5 of water. It contains therefore more oxygen and more water than the blue carbonate. The compact malachite receives a fine polish, and is sometimes used for ornamental purposes, though its softness renders it of less value.

A fossil, which has been found in different parts of Siberia, associated with malachite, and which has received the names of Diopase, Emeraudine, Copper Emerald, may be regarded perhaps as allied to carbonate of copper, from its external characters and its composition. It occurs crystallized in six-sided prisms, acutely acuminate on both extremities by three planes; is of an emerald-green colour, semi-transparent, with a vitreous lustre. It scratches glass with difficulty; has a specific gravity from 2.850 to 3.300. Fused before the blowpipe with borax, it gives a button of copper. Analysed by Vauquelin, it appeared to consist of 28.57 of oxide of copper, 42.85 of carbonate of lime, and 28.57 of siliceous earth.

Copper has been found mineralized by phosphoric acid, forming a rare ore, formerly confounded with malachite, but analysed by Klaproth, and found to consist of oxide of copper 68.13, phosphoric acid 30.95. It occurs massive, disseminated in cubic crystals very small and grouped, of a green colour internally, though generally black on the surface, with a vitreous lustre, and opaque; its fracture is fibrous. It is found near Cologne.

Copper occurs also mineralized by muriatic acid: A fossil had been brought from Peru in the state of sand, of a grass-green colour, which, when examined with the microscope, appeared to consist of transparent green par-

ticles, with quartz. It has since been obtained massive, and crystallized in six and in four-sided prisms bevelled on the extremities, transparent, with considerable lustre; when massive, it is opaque; its fracture is foliated. Urged by the flame of the blowpipe on charcoal, it gives a green flame. It dissolves in nitric and muriatic acids, without effervescence, and, distilled with sulphuric acid, exhales muriatic acid. Analysed by Klaproth and Proust, it has given nearly the same results, from 70 to 76 of oxide of copper, about 10 of muriatic acid, and from 12 to 16 of water. This acid is essential to its composition, and not derived from muriate of soda mixed with it, as Vauquelin at one time supposed.

Sulphate of copper occurs in solution, in the water of some copper-mines; and sometimes deposited stalactitic or crystallized; its crystals being either capillary, or cubes truncated on the edges or angles, of a blue colour, shining, and translucent. It no doubt derives its origin from the chemical changes which sulphuret of copper suffers from exposure to humidity and atmospheric air, particularly from the absorption of oxygen, whence sulphuric acid is formed, with which the oxide of copper combines.

Copper occurs in nature, mineralized by arsenic acid, forming combinations different with regard to proportions, and to the presence of water; for the exact mineralogical description of which we are indebted to Bournon, and for their analysis to Mr Chenevix *. These Bournon has considered as distinct species, of which there are four; but if we regard chemical composition as the base of spe-

* Philosophical Transactions, 1801.

cific distinctions in the mineral kingdom, they are probably to be considered as sub-species or varieties. It is no doubt possible, as Bournon has stated in reference to this question, that the same metal combined with the same acid may give rise to more than one species, from the different degrees of oxidizement in which the metal may exist in the combination. But there is no proof that this cause exists in the present case, nor can it well be supposed in any case to give rise to so many species. It has been supposed, that specific distinctions may arise from the chemical agency of the water in these combinations; but there is reason to doubt if water has such an important influence in the saline combinations of copper, as has been ascribed to it by Proust and Chenevix: And though there are differences of properties among the natural arseniates, these, as Haiiy has observed *, are scarcely of sufficient importance to constitute species.

The first variety of arseniated copper occurs crystallized, in the form of an obtuse octaedron. Its usual colour is sky-blue; though sometimes it is of an apple or grass green: it is translucent; shining: it is brittle; of the hardness which scratches calcareous spar, but not fluor spar; having a specific gravity of 2.881. Analysed by Mr Chenevix, it gave 49 of oxide of copper, 14 of arsenic-acid, and not less than 35 of water. The second is crystallized in very fine hexaedral tables, bevelled on the terminal planes: its colour is a deep emerald-green, with much lustre and transparency: when massive, in which state it likewise occurs, it is only translucent: it is

* Nicholson's Journal, vol. viii. p. 197.

less hard than the preceding, and likewise less heavy; its specific gravity being only 2.548. According to the experiments of Chenevix, it consists of 58 of oxide of copper, 21 of arsenic acid, and 21 of water. The same variety appears to have been analysed by Vauquelin, who states its composition at 59 oxide of copper, 41 arsenic acid. The third is crystallized in the form of an acute octaedron, or what may be regarded as an oblique four-sided prism, bevelled at both extremities, but presenting various appearances, the crystals sometimes being lengthened and capillary, but of a determinate form; sometimes capillary and indeterminate; in some specimens appearing as very delicate fibres, parallel or divergent, and in a certain degree flexible; and, lastly, sometimes in layers, flat, or mammillated, and of a fibrous texture, but compact, from the close approximation of the fibres. The colour of this variety in these different states is dark olive green, often passing into brown or yellow, or greenish-white: it is generally transparent, or semi-transparent: the lustre is externally shining: it is harder than the preceding varieties, and is much heavier, the specific gravity being 4.280. The results of the analysis of this sub-species are somewhat different. One form of it gave 60 of oxide of copper, 39.7 of arsenic acid; another, that in which the crystals are capillary and indeterminate, 51 oxide of copper, 29 arsenic acid, and 18 water; and a third, that in the hæmatitic form, 50 of oxide of copper, 29 of arsenic acid, and 21 of water. This last, Bournon has since considered as forming a species different from the others, including under it that which appears also under the form of delicate flexible fibres; the latter being supposed

to be the product of the decomposition of the former*. The last variety is that which occurs crystallized in triedral prisms, generally extremely small: they are of a beautiful bluish-green colour, but from decomposition the surface is often black: when unaltered, they are transparent. Its specific gravity is 4.280: its hardness such as with difficulty to scratch calcareous spar. It consists of 54 oxide of copper, 30 arsenic acid, and 16 water. Mr Chenevix has supposed, that the colours of all these varieties of arseniate of copper, depend principally on the water they contain; that in losing this water, they pass from the blue to pale green, and finally to brown; that only one of these varieties, the first, is a real arseniate of copper, the others containing water essential to the composition; and that there is a progression in the proportions of acid; there being one in which it amounts to 14 *per cent.*, another to 21; and a third to 29.

These varieties of arseniate of copper are found in the county of Cornwall.

Copper, in combination with Sulphur, with variable proportions of several other metals, forms a series of ores, which appear to pass into each other, and which present considerable difficulties in arranging them as distinct species. Those which appear most clearly marked, are what have been named by mineralogists, Vitreous copper ore, Variegated or Purple copper ore, Copper Pyrites or Yellow copper ore, Grey copper ore, and White copper ore. The three first consist principally of sulphuret of copper, with iron in different proportions;

* Nicholson's Journal, vol. viii. p. 259.

the fourth contains, besides these, lead, antimony, and silver; and the last appears to contain arsenic. It is not easy to determine the modes of combination of these elements; whether some of these ores are aggregates of different metallic sulphurets, or whether two or more of the metals associated are in immediate combination with each other, and with the sulphur. Bournon has regarded them as triple compounds of copper, iron, and sulphur, in different proportions; and regards the other metals contained in them as only mechanically mixed, generally also in the state of sulphuret.

The Vitreous copper ore, as it has been named, appears to be the sulphuret of copper in its purest form: as, according to its analysis by Klaproth, it consists of 78.50 of copper, 18.50 of sulphur, 2.25 of iron, and 0.75 of silex. It occurs massive, disseminated, and crystallized, the forms of its crystals being the six-sided prism, perfect or truncated on the terminal edges, the double six-sided pyramid, truncated on the extremities, the octaedron, the cube, perfect or truncated on its angles, and the three-sided table, also truncated on the angles. The crystals are small, and do not often occur. Its colour is grey, of various shades; its lustre metallic: its fracture is conchoidal or even, giving rise to what has been named compact vitreous ore, or foliated, forming another variety. It has a specific gravity from 4.1 to 5.3. Heated by the blowpipe on charcoal, it melts, exhales an odour of sulphur, and yields a metallic button, chiefly copper, with a little iron.

In the Purple, or, as it is more properly named, Variegated Copper Ore, the proportion of iron is larger, and

either it or the copper appears to be slightly oxidized, a small quantity of oxygen existing in the ore. Klaproth's analysis gave in one specimen, of copper 69.5, in another 58; of iron, in the former 17.5, in the latter 18; of sulphur in both 19, and of oxygen four or five. It is well characterized by its variegated aspect with regard to colour. The colour of a fresh fracture is reddish-brown, but it quickly tarnishes: the various tints of purple, blue, red, reddish-yellow, and green, being assumed and presented intermixed on the same surface. It occurs usually massive, sometimes disseminated, or in plates, and, as has been said, crystallized in octaedrons: its lustre is shining and metallic, but is diminished with the tarnishing: it is opaque; is soft and brittle: its fracture is minute conchoidal; its specific gravity from 4.3 to 4.9. It effervesces with nitrous acid, and gives a brown-coloured solution, and fuses before the blowpipe on charcoal, yielding a metallic globule.

Copper Pyrites is a compound of sulphur, copper, and iron; or, in another point of view, may be regarded as a combination of sulphuret of copper, and sulphuret of iron. These appear, from the analysis of different specimens, to be in various proportions. As stated by Sage, the composition is 40 of copper, 40 of iron, and 20 of sulphur; by Lampadius, 41 of copper, 17 of iron, and 45 of sulphur. Its colour, which is characteristic, is brass-yellow, being deeper as the copper is more abundant in its composition: it is generally tarnished, and often iridescent. It occurs massive, disseminated, in botryoidal and stalactitic forms, and crystallized; the forms of its crystals being the tetraedron, octaedron, dodecaedron, and

six-sided table, variously modified. Its lustre is shining and metallic ; its fracture uneven ; it is brittle, and has a specific gravity from 4.1 to 4.3. It melts before the blow-pipe into a black globule, which, by continuing the heat, assumes the lustre of copper.

The last of these sulphurets is the Grey Copper Ore, the chemical nature of which is not easily determined. It generally contains various metals combined with the sulphur and copper, and the copper is even sometimes not the one in largest proportion. Thus, in a specimen from the Hartz, analysed by Klaproth, the proportions were 34 of lead, 16 of copper, 16 of antimony, 2.25 of silver, 13 of iron, 10 of sulphur, 2.5 of silex, and 6.25 of loss : in another, from Kremnitz, 34 of antimony, 31.36 of copper, 14.77 of silver, 3.3 of iron, 11.5 of sulphur, and 4.98 of loss. But what proves that it is still to be properly regarded as a copper ore, is, that these other metals are in very variable proportions, and are often even altogether absent ; hence they can be regarded as only accidental. When they are present, too, they alter little the characteristic qualities of the mineral ; while, if they were real constituent principles, the absence or presence of one or more of them ought, as Bournon has observed, to give rise to some perceptible difference. From these facts, this distinguished mineralogist concludes, apparently with justice, that copper and iron combined with sulphur, is the composition which essentially constitutes the grey copper ore, and that the others are accidentally received into its composition, without being chemically combined. It exists, as appears from the analyses of the different varieties of

it by Mr Chenevix, of this composition alone; the proportions being in one specimen distinctly crystallized, 52 of copper, 31 of iron, and 14 of sulphur. And in a number of other specimens, lead and silver were altogether wanting, and antimony, though present, was in variable proportions from 10 to 38 in 100. The former analysis may perhaps, therefore, be regarded as giving the true composition of the species*.

Grey copper ore occurs massive, disseminated, and crystallized; the principal form of its crystals being the tetraedron or three-sided pyramid, variously modified. Its colour is steel-grey, passing into various shades of grey, and liable to tarnish: its lustre is shining and metallic: its fracture uneven: it is brittle; and has a specific gravity from 4.4 to 4.8. It decrepitates when heated by the blowpipe, and melts, giving a metallic globule.

What has been named White Copper Ore, has not been accurately analysed, but it appears to contain a portion of arsenic, from the odour it exhales when heated by the blowpipe, in combination with copper, and probably iron, and sulphur. Its colour is white, with a shade of grey or yellow: its lustre is metallic: it is brittle; and has a fine-grained uneven fracture: it occurs either massive or disseminated, and is a very rare ore.

The name of Black Copper Ore has been given to a substance occurring as an incrustation, sometimes massive, and composed of loosely cohering particles of a brownish-black colour, without lustre, which has probably its origin in the spontaneous decomposition of grey

* Philosophical Transactions, 1804, p 52.

copper ore, or some of the other ores of the same family. It is usually associated with them.

The various sulphurets of copper are the most abundant of its ores, and of these the most so is copper pyrites. The malachite, red copper ore, and others, are generally associated with these in small quantities. Copper-mines are worked in so many countries as to require no enumeration. Those of Sweden furnish the purest copper of commerce.

SECT. VI.

OF ORES OF IRON.

OF all the metals, iron is the one which is most extensively diffused : there are, indeed, few mineral substances entirely free from it. It forms, too, a very extensive family of ores, some of which are found in almost every country ; and the singular fact has been established, that it is even an atmospheric production ; those masses, which, it is now established by very ample evidence, have fallen from the atmosphere in various countries, at various periods, being composed of iron alloyed with a small portion of nickel, and accompanied with smaller quantities of some other substances. As a natural combination of iron, the chemical history of this meteoric iron, as it has been named, may be given with that of the other natural combinations of the metal.

The phenomenon with regard to the fall of these masses of iron from the atmosphere, however singular and un-

accountable it may appear to be, is now established on evidence which cannot be controverted. A number of facts with regard to stones descending from the atmosphere, had been from time to time recorded in the memoirs of the different learned societies in Europe; but the stones themselves had not been subjected to any accurate chemical examination. This was at length done by Mr Howard *. Having procured specimens of stones, ascertained by unexceptionable evidence to have recently fallen from the atmosphere near Sienna in Italy; in Yorkshire; near Benares in India; and in Bohemia; he submitted them to analysis: they all afforded iron alloyed with nickel, and containing a portion of silex and magnesia.

These masses are heterogeneous in their structure. They are covered externally with a thin black crust, and their surface is rough. When broken, they are of an ash-grey colour, and granulated texture, and appear to be composed of four different substances, which can only be distinguished by a lens. One of these substances is in the form of small globular or elliptical masses, of a grey colour, having a conchoidal fracture, smooth even grain, a lustre resembling that of enamel, and so hard as to scratch glass: it has a resemblance in characters and composition to the fossil named Chrysolite. Another consists of iron pyrites of a reddish-yellow colour, and granulated texture. The third consists of small particles of iron in a metallic state, capable of being extended under the hammer, and giving to the entire stone the property of being attracted by the magnet: the proportion of this varied considerably

* Philosophical Transactions, 1802, p. 168.

in the different specimens : in that from Bohemia, it amounted to $\frac{25}{1000}$. These three substances are united by a fourth, which is nearly of an earthy consistence. Both the metallic pyrites and the iron contain nickel, the proportion of sulphur in the pyrites being very small. The vitrified substance, the first of the four above described, consists of silex, magnesia, oxide of iron, and a little nickel. The composition of the earthy matter was nearly the same, and it appeared to differ principally in its state of aggregation. The external crust consisted of iron and nickel partially oxidized. In all the specimens the same elements were found, and in proportions not very different ; and this agreement in fossils, found in countries so remote, is a strong proof of their common origin. It has also been extended and confirmed by experiments made on other meteoric stones by Vauquelin and Klaproth *. From an analysis by Laugier, chrome also appears to be an ingredient in these stones †.

There is every reason to believe, that the large insulated masses of iron which have been observed in America and Siberia have had the same origin. Proust, in analysing a fragment of that from America, previous to Mr Howard's investigations, found it to contain nickel ‡. Mr Howard, on repeating the analysis, likewise ascertained this ; 100 grains giving $7\frac{1}{2}$ of nickel. That from Siberia, Mr Howard equally found to contain nickel. And both these masses also have a vitrified matter, re-

* Philosophical Magazine, vol. xv. and xvi.

† Nicholson's Journal, vol. xv. p. 147.

‡ Nicholson's Journal, 4to, vol. iv. p. 356.

sembling chrysolite, intermixed in their substance, analogous to that present in the meteoric stones. Both, too, are of such a size that they could not have been the produce of art; and they are perfectly insulated, at a distance from any mountain, or any volcano, from which they might have been supposed to be derived. These facts leave no room to doubt but that they are similar productions.

The iron of these masses has a specific gravity of only 6.4. The fresh fracture presents a silvery-white colour: its grain is smooth and fine, and it is malleable.

From a number of the accounts that have been authenticated with regard to the fall of these masses, it appears that they have been highly heated, and probably in a state of fusion. The stone, when touched after its fall, has been felt quite hot, and the external crust has appeared newly vitrified. The fall has also been frequently accompanied with the appearance of a fiery meteor, as of a luminous ball, and sometimes with discharges of lightning, and with a loud noise, or repeated explosions*.

With regard to the origin of these masses, it is extremely difficult to advance any hypothesis at all satisfactory. That they have been projected by volcanic eruptions, is a supposition that might occur; but their fall in countries so remote from any volcano, the horizontal motion which some of them have been observed to

* A very interesting account of a fall of meteoric stones, at Weston in North America, where the phenomena accompanying it were attentively observed by a number of individuals, has been lately given by Professor Silliman*.

* Philosophical Magazine, vol. xxx. p. 232.

hold previous to their descent, and their total dissimilarity to volcanic products, sufficiently disprove this hypothesis. La Place advanced the bold conjecture, that these masses have been projected from the moon, and, by a mathematical calculation, has endeavoured to show that this might happen, since, if a mass were projected by any cause, as a volcanic eruption, from that planet, with a velocity of a mile and a half *per* second, (which is possible, as this does not greatly exceed that of a ball issuing from the mouth of a cannon, which, according to Dr Hutton, who has supported the hypothesis of La Place *, may be projected with the velocity of half a mile in a second), it would be thrown beyond the sphere of the moon's attraction, and within that of the earth's, and of course would fall with increased velocity to its surface. That such a force may be exerted at the moon is possible ; and that such volcanic eruptions, or similar convulsions, may be exerted, has been supposed to be rendered probable, by the appearance of change which astronomical observations have discovered on the moon's surface. This calculation proceeds, however, on the supposition, that the moon has no atmosphere to oppose resistance to the projectile ; and that this is the case, has been supposed to be rendered probable from optical considerations †. This, however, is far from being proved. Unless every substance composing that planet be actually solid, an atmosphere must be formed around it, by the transition, under the total absence of pressure, of any fluid whatever into vapour: and the very hypothe-

* Abridgement of the Philosophical Transactions, v. vi. p. 100.

† Ibid. vol. vi. p. 104.

sis of volcanoes operating and throwing out such substances, effectually precludes the supposition, that the whole of the matter of that planet is in a solid state.

According to another opinion, these masses have been formed by combinations in the upper regions of the atmosphere. This also is somewhat vague, and altogether hypothetical; it is not easy to conceive, how, from the rare elastic fluid in these regions, such a quantity of dense matter should be deposited or formed; nor does the hypothesis account well for the fact generally observed with regard to the fall of these masses, that they move in a curve, or sometimes nearly in a horizontal line, previous to their descent.

Native iron, independent of these meteoric iron stones, has been supposed to exist. Immense masses of this metal have been observed on different parts of the earth's surface, which, from their situation and characters, it is impossible could have been the produce of art. One mass, calculated to be at least 1600 lbs. weight, lies insulated in a district in Siberia; another was observed in Peru, at least 300 lbs. With regard to these, however, there is every reason to conclude, that they are meteoric iron; as both of them, according to Proust's and Klaproth's analyses, contain nickel; and the Siberian mass has even the vitrified-like crust. It has farther been stated, however, that specimens of malleable iron have been found imbedded in different iron ores; and Klaproth has given the analysis of a specimen of this kind, found in a mine of Saxony, which he found to consist of 92.5 of iron, 6 of lead, and 1.5 of copper. But the facts with regard to these can scarcely be considered as sufficiently authenticated.

The most abundant and most numerous ores of iron, are those in which it is mineralized by oxygen. Of these native oxides there is a series; the individuals of which differ in the quantity of oxygen they contain, and in containing various other substances. They are to a certain degree discriminated by the peculiar property which iron possesses,—that of magnetism. This belongs to the pure metal: it is not destroyed by the addition of a small quantity of oxygen. But the addition of a large proportion weakens or destroys it, as does also the intermixture of sulphur, arsenic, manganese, or antimony. It is difficult to fix the limits of the members of the series, or to form them into well-defined species, since they pass so closely into each other. It may be done partly from their chemical relations, and partly from their external characters.

One species well-defined, is that named Magnetic Iron Ore, from its magnetic power, which is always such that it is attracted by the magnet, and is often so great, that it acts as a magnet, or attracts iron. It occurs massive and crystallized: the forms of its crystals being the cube, octaedron, and rectangular tetraedral prism, which is acuminate by four planes. The crystals are generally small and aggregated. Its colour is black or deep grey: the same colour remains in the streak or in the powder: its lustre is shining and metallic; and it is opaque: its fracture is fine or coarse grained uneven, or imperfectly foliated: it is brittle; and hard; sometimes so much so, as to give sparks with a flint: its specific gravity is from 4.2 to 4.9: it is insoluble in nitric acid, but dissolves in muriatic acid, with the assistance of heat. When exposed to the flame of the blowpipe, it becomes brown, and gives

to borax a dark-green tinge. It yields from 80 to 90 in 100 of iron, and may be regarded as a pure oxide. It is a very abundant ore, or is very widely diffused, and affords in working a very pure iron. The Swedish iron is principally extracted from it.

It sometimes occurs in the form of small particles or grains, having nearly the characters above stated. It is then named Magnetic Iron Sand.

The next species is equally determinate,—that which from its high lustre has received the name of Specular Iron Ore, or Iron Glance. In it the magnetic power is so far impaired by a higher degree of oxidizement, that it is attracted by the magnet only when reduced to a fine powder. It occurs massive, and also frequently crystallized: the forms of its crystals are numerous, and variously modified: the principal are the double triaedral pyramid, the six-sided table, the lens, the double six-sided pyramid, the six-sided prism, and the cube. Its colour is steel-grey; but is often tarnished and iridescent. The colour is red in the streak, and in the powder: the lustre is highly shining and metallic: its fracture is uneven fine or coarse grained, sometimes foliated: it is so hard as to scratch glass; and at the same time is brittle: its specific gravity is from 4.6 to 5.2. Like the preceding species, it is insoluble in nitric acid; but dissolves in the muriatic acid, with the assistance of heat. It reddens before the flame of the blowpipe, and gives to borax a dull yellow hue. According to Mr Kirwan, it consists of from 60 to 80 of iron, and from 20 to 30 of oxygen. It is found in a number of countries; in great abundance in the island

of Elba, whence very fine specimens are brought. It affords very pure malleable iron.

What has been named Micaceous Iron Ore, has been regarded as a variety of this species. It is massive, disseminated, or crystallized, in small and thin six-sided plates: it is shining; and feels somewhat greasy, but without staining the fingers; and is not so hard as the specular iron ore: its fracture is foliated. According to Bournon *, this belongs to a distinct species, in which the oxidation is higher than in the specular iron ore, so that the magnetic power is altogether lost; being the last of the series of the oxides of iron capable of crystallizing, and intermediate between these, and those which occur only in indeterminate forms. The primitive form of the crystals is a cube, while that of the specular iron ore is a rhomboid. Its hardness is inferior, and its specific gravity low, being only 3.96. Its powder is more red than that of the specular, but has not the yellow cast observable in the powder of the hæmatite.

The next family of ores it is more difficult to arrange as species. The iron is in a higher state of oxidizement; and the oxide is at the same time mixed with variable quantities of other substances, principally argil, silex, and lime. These ores are therefore not magnetic; but the greater number of them acquire that property by being heated strongly on charcoal by the flame of the blowpipe. Their chemical distinctions and composition have been very imperfectly determined: their arrangement as well-defined species is difficult, from their passing so closely

* Philosophical Transactions, 1803, p. 336.

into each other ; and the species have been perhaps unnecessarily multiplied.

Of what is named by Werner Red Ironstone, there are two principal varieties, distinguished chiefly from the fracture,—the compact red ironstone, the fracture of which is even ; and the hæmatite, the fracture of which is fibrous, the fibres being straight, parallel, or diverging. The former occurs generally massive, or in detached masses, nodular, stalactitic, &c. ; sometimes crystallized in aggregated cubes ; the latter almost always in globular or kidney-shaped masses, stalactitic or botryoidal. The colour of both is intermediate between brownish-red and steel-grey ; but in the streak, and in powder, always blood-red ; it is accompanied with little lustre, except in the crystals *. Their specific gravity is from 3.5 to 5. They blacken when heated before the blowpipe, and give to borax a yellowish-green tinge. Their chemical analysis has been very imperfectly executed : they contain silica and argil, with oxide of iron, and when worked, afford about 60 parts of iron from 100 of ore, in general of excellent quality. It is one of the most abundant of the iron ores. Under the same species have been placed other two varieties of less importance, Red Scaly Iron Ore, which occurs generally as an incrustation on other iron ores, and is composed of scaly particles of a red colour, with a kind of silky lustre, feeling somewhat unctuous, and staining the finger ; and the Red Ochre,

* The crystallized variety is considered by Bournon as belonging to the new species he has described, together with what was called the Micaceous Iron Ore.

which occurs earthy, or slightly indurated, of a red colour, with no lustre, which soils, but feels rather harsh than unctuous. These frequently accompany the two principal varieties of the species.

The ore to which the name of Brown Ironstone has been given, is distinguished from the preceding, principally by the colour being brown in the mass, and in the streak yellow or yellowish-brown. Of it too, there are two principal varieties, distinguished by the fracture,—the compact brown ironstone, the fracture of which is even; and the brown hæmatite, the fracture of which is fibrous, the fibres being of different degrees of fineness, seldom parallel, but in general diverging. The compact occurs massive, sometimes in masses of various imitative forms. The fibrous occurs generally in masses, stalactitic, kidney-shaped, botryoidal, tuberosc, &c.; sometimes in supposititious, or even in very minute true crystals. The colour of both is brown, of various shades and intensities, sometimes tarnished, so as to be iridescent, with a degree of lustre that is semi-metallic. The specific gravity is about 3.4 or 3.5. It is blackened when urged by the flame of the blowpipe, and gives to borax a green colour. Its analysis has not been executed with any accuracy, but it appears to contain, with oxide of iron, argil, lime, and oxide of manganese. It yields from 40 to 60 of iron, which is said to be well adapted to the manufacture of steel. Under this species too, are arranged two less important varieties,—the Brown Scaly Iron Ore, and the Brown Iron Ochre;—the former generally incrusting the other ores of the species, or lining their cavities, and, like the red scaly ore, being composed of scaly particles, which

have a shining lustre, soil, and feel unctuous; the latter being earthy and little indurated, of a yellowish-brown colour, dull, and staining the finger.

Black Ironstone, like the red and brown, comprises two principal varieties,—the compact, and the fibrous or black hæmatite. It is, however, under either form a rare ore. Its colour is bluish-black, or dark steel-grey, with a semi-metallic lustre: in the streak it is shining, and the colour remains unchanged. It occurs massive, and in tuberoso, kidney-shaped, and botryoidal pieces. It gives a blue colour to borax in fusion. Its composition is not known, but it is supposed to contain a large proportion of oxide of manganese.

An extensive family of ores is comprised under the species which has been named Argillaceous Iron Ore, or Clay Ironstone, in which oxide of iron is mixed with a large proportion of argil or clay, and of which the principal varieties only can be noticed; nor are the limits of these easily marked, as a number of them pass into each other. The common argillaceous ironstone occurs massive, generally in beds or strata, frequently also, as forming the substance of petrifications, or with vegetable impressions. Its colour is grey, of different tints, which passes into various shades of a yellowish or reddish-brown, especially from exposure to the air: it has no lustre, and is perfectly opaque: its fracture is earthy; sometimes even; sometimes inclining to the slaty: it is soft, feels meagre, adheres a little to the tongue: its specific gravity is about 3.3 or 3.4. Before the blowpipe it becomes black; and fused with borax, it gives a dark-green glass. It consists of oxide of iron, clay, with portions of lime, and silex;

and, in the different varieties, with various other intermixtures. It affords from 30 to 40 of iron in 100, of good quality. In this country it is very abundant, occurring often with beds of coal, and is the ore that is principally wrought.

Some other varieties of this species may be pointed out. What has been named the Nodular Ironstone, reniform iron ore, or eagle stone, occurs in rounded masses, sometimes spherical, generally somewhat oblate, or approaching to the kidney form. These are composed of concentric lamellar concretions, and sometimes inclose a nodule slightly adhering or quite loose. In its general characters it is similar to the common argillaceous ironstone : it is of common occurrence in this country, and, when wrought, affords excellent iron. The Pisiform Iron Ore is in small rounded grains, whence its name ; of a yellowish-brown colour, having an earthy fracture, with little coherence. It has been analysed by Vauquelin, and gave 30 of iron, 18 of oxygen, 31 of argil, 15 of silex, and 6 of water. The Lenticular Argillaceous Iron Ore, is so named from occurring in lenticular distinct concretions; is of a brownish-red colour, and a lustre which is semi-metallic. Red Chalk, or Reddle, which is used for forming crayons, has also been placed under this species. It has little coherence ; but is ductile, soils strongly, adheres to the tongue, feels meagre, and is of a red, or brownish-red colour, without lustre.

What has been named the Sparry Iron Ore, is a species well determined from its chemical relations. It consists of oxide of iron, oxide of manganese, and carbonate of lime, or rather perhaps the carbonic acid may be in com-

bination with the lime and the two metallic oxides. The proportions of these vary, and the carbonate of lime augments in some varieties so much, that they are not regarded as iron ores, but are placed among the calcareous fossils, forming what is named, from its peculiar lustre, Pearl Spar. There is thus an extensive series, and it is only when the proportion of metallic matter is abundant, that it is regarded as an iron ore. In this state it occurs massive, disseminated, and crystallized : the forms of its crystals being the rhomb, perfect or truncated, the lens, the octaedron, and the dodecaedron. Its colour is white, grey, yellow, or brown ; but what is a very peculiar property of it, the colour darkens from exposure to the air : it thus becomes brown, and at length black,—a change owing to the manganese existing in it being in a low state of oxidizement, and absorbing oxygen from the atmosphere, until it pass to the state of the perfect oxide : its lustre is pearly ; it is translucent on the edges : its fracture is foliated : its fragments are rhomboidal : it is harder than calcareous spar, so as to scratch it : its specific gravity is from 3.6 to 3.8 : it is soluble with effervescence in acids. It blackens before the blowpipe, and loses weight. Analysed by Bergman, it afforded, in different specimens, from 22 to 38 of oxide of iron, from 24 to 28 of oxide of manganese, from 19 to 24 of lime, from 10 to 17 of carbonic acid, and from 9 to 6 of water ; but in the different varieties of it, the proportions of its constituent parts are extremely various. Descostils has found magnesia in it, and has farther discovered, that it is from the presence of this earth that some varieties of this ore are extremely refractory in the fire, so as scarcely to ad-

mit of being worked *. It is considered as affording the iron best adapted to the manufacture of steel.

Oxide of iron deposited from water holding it in solution and stagnant in swampy situations, forms what has been named as a species Bog or Swamp Iron Ore. It is of course always found at, or immediately under the soil; is in different degrees of induration, in masses which are corroded, cellular, and sometimes tuberoso. It is of a yellow or brown colour, dull, or when indurated having a degree of lustre which is resinous. Its fracture is earthy, but, where the induration is greatest, passing into minute conchoidal or even. Its composition is not well determined; but it has been supposed to contain, with oxide of iron, argil, silex, and phosphoric acid. Vauquelin has examined some bog iron ores, and along with those ingredients discovered in them lime, magnesia, manganese, and chrome.

What has been named Blue Iron Earth, is probably of similar origin, as it is associated with bog iron ore, or deposited amid turf and peat, and, according to Haüy, consists of oxide of iron, with argil, and a little phosphoric acid; though Vauquelin, it may be remarked, found in it only oxide of iron, argil, and silex. It is at first of a white colour, but becomes blue from exposure; is loose and friable without any lustre. Before the blowpipe it loses its colour, becomes brown, and at length gives a globule which is magnetic. It is also soluble in acids.

What has been named Green Iron Earth, has likewise been supposed to consist of iron and phosphoric acid. It is earthy, more or less coherent, of a green colour, without

* Nicholson's Journal, vol. xviii. p. 315.

lustre. It becomes red before the blowpipe, but is not fused : to borax it gives a yellowish-green tinge. This, which is a rare mineral, is found in veins in some districts of Germany.

An ore in which the presence of phosphoric acid is less ambiguous, has been found in France, and analysed by Vauquelin. It was found to consist of 27 of phosphoric acid, 31 of oxide of iron, and 42 of manganese. It is found massive : its fracture is compact, passing to foliated : it is semi-hard ; its colour is a deep reddish-brown ; its external surface dull, but internally it has more lustre, which is semi-metallic. It melts very easily before the blowpipe into a black enamel.

Iron mineralized by phosphoric acid alone, forming nearly a pure phosphate, has more recently been discovered to be a natural production. This mineral was brought from the Isle of France. It is of a deep blue colour, is in small plates adhering slightly, which appear to be quadrangular prisms much compressed : the surface of the plates is brilliant : they are translucent, but some, apparently from the loss of the water they contain, are opaque. The specific gravity is 2.6. Urged by the flame of the blowpipe, the colour becomes yellow, and at length a globule having metallic brilliancy is obtained. Nitric acid forms a perfect solution. Vauquelin recognised this fossil to be similar in its external characters to another, which he had received from Abildgaard, under the name of Phosphate of Iron of Brasil, and like it too, it was found to be soluble in nitric acid without any residuum. It was then analysed by Fourcroy, who found it to consist of 41.25 of iron, 19.25 phosphoric acid,

31.25 water, 5 argil, 1.25 of silex, somewhat ferruginous, with two parts of loss *.

Iron has been found in Cornwall, mineralized by arsenic acid, forming an ore formerly regarded as an arseniate of copper, but recognised to be an arseniate of iron, described by Bournon, and analysed by Chenevix. It occurs massive, but generally crystallized in small cubes, the surfaces of the sides of which are smooth, and highly shining. The lustre is adamantine: the colour is a dark green, sometimes with a brown or yellowish tinge, and in the streak is straw-yellow. The crystals are translucent. The fracture is imperfect foliated; the specific gravity 3000. Analysed by Chenevix, this species was found to consist of 31 arsenic acid, 45.5 oxide of iron, 9 oxide of copper, 4 silex, and 16.5 of water. The copper, Mr Chenevix regards as accidental, not essential to the composition. Another ore was discovered, however, in which the copper was more constant and in larger proportion, the proportions being 33.5 arsenic acid, 27.5 oxide of iron, 22.5 oxide of copper, 3 of silex, and 12 of water. This species occurs in minute crystals, the form of which is a rhomboidal tetraedral prism, acuminate at each extremity by four planes. Their colour is a faint sky-blue; they are perfectly transparent, and of very high lustre. They are generally grouped irregularly, sometimes united so as to assume a mammillary form. They are rather harder than the simple arseniate of iron. The specific gravity is 3.4.

Sulphate of Iron sometimes occurs in tuberoso or stactitic masses; sometimes in capillary crystals, in im-

* Annales de Museum National, tom. iii. p. 405.

perfect rhombs, or in octaedrons; of a green colour, easily recognised by its solubility in water, its astringent test, and the usual chemical tests of the salts of iron. It obviously derives its origin from the decomposition and oxygenizement of native sulphuret of iron, with which it is generally associated.

Chromate of iron, or the metal mineralized by chromic acid, rather belongs to the ores of chrome.

Iron, in combination with sulphur, forms a well-defined species, that which has been long known under the name of Pyrites, and which is very extensively diffused. It occurs massive, disseminated, and frequently crystallized: the forms of its crystals are various, but the most common is the cube regular, or modified by truncation of the angles or edges, or acumination of three planes on the angles: the octaedron, dodecaedron, and icosaedron, also sometimes occur. Its colour is brass yellow, varying a little in the shade, and the lustre is always fully metallic: it is opaque. The fracture is uneven. It is brittle; its hardness is such as to strike fire with steel; its specific gravity is from 4.6 to 4.8. By friction it exhales a sulphurous smell. This odour is strong when it is heated before the blowpipe; it gives at the same time a blue flame; and at length a globule of a brownish colour. It is soluble in nitric acid, with the disengagement of red vapours. It is not sensibly magnetic. Various analyses of it have been given: according to those executed by Mr Hatchet, it consists of 52 of sulphur, with 48 of iron.

Besides this, which may be named Common Pyrites, there are some others which may be regarded as varieties

of the species, and which differ principally in structure, or the form under which they occur. The Striated or Radiated Pyrites presents a striated fracture, the striæ being generally diverging. It is rather more liable to tarnish than the preceding, and decomposes more readily in a humid atmosphere. According to Mr Hatchet's analysis, it consists of 53.6 or 54.3 of sulphur, with 46.4 or 45.6 of iron. The Capillary Pyrites occurs in delicate capillary crystals, grouped, parallel, diverging, or interwoven, slightly flexible, having a metallic lustre, and a colour passing from yellow to steel-grey. There is, lastly, the Hepatic Pyrites, so named from the liver-brown colour, which it assumes from exposure to the air. In the fresh fracture its colour is pale brass-yellow, inclining to steel-grey. It occurs massive, of various imitative forms, and crystallized in six-sided prisms, or six-sided pyramids : it has less lustre than the others, and is more subject to decomposition.

What has been named Magnetic Pyrites, distinguished, as the name implies, by its magnetic quality, of which the others are destitute, has been considered as forming a distinct species. Its colour is deeper, being intermediate between brass yellow and copper red, and approaching even to brown, often tarnished : its lustre is also inferior, but is still metallic. It occurs only massive or disseminated. Its fracture is compact : it is hard and brittle : its specific gravity is 4.5. It appears, from Mr Hatchet's analysis of it, to differ from the other iron pyrites, in containing a larger proportion of metal, to which, no doubt, its quality of being attracted by the magnet is owing. The proportions of its constituent

parts he found to be 36.5 of sulphur, and 63.5 of iron. He observes also, that it resembles in its properties the sulphuret of iron that is artificially formed.

There has been considerable difference of opinion, among chemists, with regard to the state of the metal in iron pyrites, whether it is oxidized or not. By Bergman, Scheele, and others, the iron was supposed to be in the calcined or oxidated state. Several arguments in support of the opposite opinion were stated by Mr Kirwan*. More lately Vauquelin, in his memoir on the metallic sulphurets †, affirmed, that the iron in pyrites is oxidized nearly to the point at which it is easily soluble in acids, while in the artificial sulphuret it is in the metallic state. Hence, says he, the reason why the natural pyrites is not decomposed by the muriatic acid, while the artificial sulphuret is with rapidity; the metal in the latter, aided by the affinity of the acid, attracting the oxygen of the water. Proust, on the contrary, affirms, that in pyrites the iron is entirely in the metallic state. When subjected to distillation, sulphur only was afforded; and the residual matter, he inferred from its resemblance to the artificial sulphuret, did not contain oxygen. By depriving the pyrites of part of its sulphur, or what amounts to the same, increasing the proportion of iron, it becomes capable of being acted on by muriatic acid, and of affording sulphuretted hydrogen in the same manner as the artificial sulphuret. It is therefore to be regarded as a super-sulphuret of iron ‡. The opinion, that the iron in pyrites is

* Elements of Mineralogy, vol. ii. p. 82.

† Nicholson's Journal, 4to, vol. v. p. 115.

‡ Ibid. 8vo, vol. i. p. 111.

in its metallic state, is also confirmed by the results of Mr Hatchet's analysis of its different varieties *.

An interesting fact has been established by the observations of Mr Wiseman, confirmed by the researches of Mr Hatchet, with regard to the origin of iron pyrites. Mr Wiseman observed, that flints, or other stones, kept for some time immersed in the stagnant water of the Mere of Diss in Norfolk, were covered with a metallic stain, or coating. This Mr Hatchet found to be iron pyrites; and the formation of this substance in the humid way has thus been established †.

It is from the different species of ores of which the oxides of iron are the base, that the metal is extracted, as has been stated under its history. From the spontaneous decomposition of the sulphurets on exposure to air and humidity, sulphate of iron is procured.

SECT. VII.

OF ORES OF LEAD.

THE existence of native lead, which has been maintained by some mineralogists, is extremely doubtful. And what has been considered as a native oxide of the metal, appears to be rather an earthy carbonate, or the pure carbonate mixed with silex or argil.

The ore in which lead is mineralized by carbonic acid,

* Philosophical Transactions, 1804, p. 325.

† Ibid. 1798, p. 567.

the White Lead Ore of mineralogists is very abundant, and is presented under different forms,—earthy, indurated, and crystallized. In the last state, it appears under the forms of the hexaedral prism, acuminated by six, and by four planes; the tetraedral prism, either bevelled, or acuminated by four planes; the double hexaedral pyramid; the four and the six-sided table; and, lastly, in acicular crystals, aggregated, and intersecting each other. The surface of the crystals is highly shining, the lustre being adamantine; the colour generally white, sometimes grey, yellowish, or brown: they are transparent, or translucent: the fracture is conchoidal: they are brittle, and soft, so as to be easily scratched by the knife. The specific gravity is from 6 to 7. Carbonate of lead, when massive, in which state it likewise occurs, has less lustre and transparency. It also occurs stalactitic, and evidently a deposit from aqueous solution.

Carbonate of lead, urged by the flame of the blowpipe, decrepitates, becomes yellow or red, and at length fuses into a metallic globule. It effervesces with acids, and, in diluted nitric acid, is completely dissolved. Its surface is blackened by the vapours which exhale from sulphuretted hydro-sulphuret of ammonia. Its composition varies with regard to the proportions of its constituent parts; and it often contains variable quantities of oxide of iron, argil, silex, and lime. Pure carbonate of lead, from Lead-hills in this country, analysed by Klaproth, was found to be composed of 77 of lead, 5 of oxygen, 16 of carbonic acid, and 2 of water.

What has been named Earthy Lead Ore, and which occurs friable or indurated, of a grey colour, of various

shades and intermixtures, without lustre or transparency, is considered as a mixture of carbonate of lead, with various earthy matters, and cannot properly be regarded as a species. When associated with an ochrey earth, so as to assume a red colour, it has been named, but improperly, Native Minium. Black Lead Ore, as it has been named, from its colour, appears to be carbonate of lead, altered probably by the action of sulphur, or by intermixture with it, especially as it is found generally incrusting the native sulphuret, and is itself incrustated by the carbonate. It is of a greyish-black colour, but gives a greyish-white streak: is shining, its lustre being adamantine, and is translucent on the edges. It occurs massive, and crystallized in six-sided prisms.

Mr Chenevix has given the analysis of an ore of lead, in which carbonic and muriatic acids are present, in the proportion of 6 of the former, and 8 of the latter, with 85 of oxide. It occurs crystallized in cubes, perfect or truncated; is similar, in its general appearance, to some of the native carbonates of lead, so as to have been ranked with them, but is softer, and has a less specific gravity; has more lustre; and is of a straw colour, or sometimes colourless, or of a transparent white. It has been found in Derbyshire*.

Lead occurs mineralized by sulphuric acid. This ore is always crystallized; the form of the crystals being the octaedron, sometimes modified by truncations of the common base, or bevellment of the angles of that base. Its colour is white, with shades of grey: the crystals are

* Nicholson's Journal, 4to, vol. iv. p. 319.

transparent, or semi-transparent; their lustre shining and adamantine; the fracture compact; the specific gravity 6.300. It is distinguished from carbonate of lead, to which some forms of it have a resemblance, by its chemical qualities: it does not effervesce; is not soluble in nitric acid; and is more quickly reduced before the blowpipe to the metallic state. It was first discovered in the Paris mine in the isle of Anglesea. It is also found at Leadhills. A specimen from the former place, analysed by Klaproth, gave oxide of lead 71, sulphuric acid 24.8, water 2, oxide of iron 1. Another from Leadhills gave the same proportions within a few fractional parts, but without the iron.

Native Phosphate of Lead, is the most abundant metallic ore in which phosphoric acid is the mineralizer. Its usual colour is green, of various shades; but it sometimes passes through yellowish-green into pure yellow. It occurs in general in an incrustation, often mammillary or botryoidal, composed often of minute crystals, more or less aggregated, the form of which is the hexaedral prism, short, with the edges truncated, or acuminate, and the hexaedral pyramid. They have a waxy lustre, and are translucent: the fracture is uneven: it is brittle and soft; but rather harder than the carbonate, so as to scratch it. The specific gravity is from 6.2 to 6.9. It does not decrepitate before the blowpipe, but becomes white, and melts easily into a globule of a grey colour, without the lead being reduced. It does not effervesce with nitrid acid, but is dissolved by it. Analysed by Klaproth, it was found to consist of oxide of lead, in various specimens, from 78 to 80, phosphoric acid 18 or 19, muriatic acid 1.5 or 1.7.

and a minute trace of oxide of iron. Vauquelin in one specimen found a considerable proportion of siliceous matter.

An ore named Brown Lead Ore, from its colour, and which occurs massive, and crystallized in hexahedral prisms, having a waxy lustre, and nearly opaque, has been found by Klaproth to consist of oxide of lead 78.58, phosphoric acid 19.73, muriatic acid 1.65. It belongs, therefore, to the preceding species.

What has been named Blue Lead Ore, from its blue colour, which is accompanied with a metallic lustre internally, though externally dull, and with perfect opacity, has been supposed to be phosphate of lead that has undergone some alteration, as its crystallization is the same, and Klaproth even found in it phosphoric acid. From exhaling a sulphureous vapour before the blowpipe, it evidently contains sulphur.

Fourcroy has given the analysis of an ore, which occurs in mammillary masses of a yellowish-green colour, and in which the oxide of lead was found to be mineralized both by phosphoric and arsenic acid, with the addition of a little oxide of iron. Lead has also been announced to occur mineralized by arsenic acid alone. Its colour is green, which passes to yellow: it occurs in acicular or capillary crystals, which are semi-transparent, and also massive. Another variety of native arseniate of lead, with an intermixture of iron, occurs in uniform masses of a rough surface and yellow colour, opaque and dull. These are all distinguished by the strong arsenical odour they give when heated on charcoal by the blowpipe.

A species has been known to mineralogists, under the name of Yellow Lead Ore, in which the lead is minera-

lized by a particular metallic acid,—the Molybdic Acid. It occurs sometimes massive, more commonly crystallized in small crystals, the forms of which are, rectangular tables of four sides, or of eight sides, bevelled, the cube, octaedron, and double eight-sided pyramid. Its colour is wax-yellow, and its lustre distinctly waxy: it is translucent, is soft, and easily broken down. It decrepitates before the blowpipe, then melts into a globule of a grey colour, in which are disseminated particles of metallic lead. It gives a bluish white colour to borax; is insoluble in nitric acid. Klaproth first discovered the molybdic acid or oxide in it; combined, according to his analysis, with 64.42 of oxide of lead. It has also been analysed by Mr Hatchet, who states its composition to be oxide of lead 58.40, molybdic acid 38, oxide of iron 2.08, and silex 0.28. It is found principally in Carinthia.

An ore had been brought from Siberia, under the name of Red Lead, in which Vauquelin first discovered the existence of the new metal, chrome, which exists in it in the state of an acid, combined with oxide of lead. As the chrome is the more important principle, it rather falls to be described under the history of that metal.

Lead, mineralized by sulphur, forms by far the most abundant ore of the metal, long known to mineralogists by the name of Galena. It occurs under almost every form, massive, disseminated, incrusting, in corroded or reticulated masses, in grains, and crystallized. The forms of its crystals are the cube perfect, or with the angles or edges truncated, the octaedron perfect or truncated on the angles or edges, the tetraedral prism acuminated by four planes, the hexaedral prism also acuminated

by four planes, and the three-sided table bevelled on the terminal planes. The colour of this ore is bluish or lead-grey, sometimes inclining to black, and sometimes also iridescent on the surface. Its lustre is splendid, and completely metallic: it is perfectly opaque: its fracture is distinctly foliated: its fragments of a cubical form: it is soft, so as to be easily scratched: it is also easily frangible: its specific gravity is from 7 to 7.7. It decrepitates before the flame of the blowpipe, then melts, exhaling at the same time a sulphureous odour, and at last affords a globule of lead. The proportions of lead and sulphur vary considerably; that of the lead is from 50 to 83, of the sulphur from 10 to 25. It always contains too a small quantity of silver; and frequently iron, silix, and lime. Those varieties which contain silver have most lustre.

A sub-species has been formed, distinguished principally by the fracture, which is compact; hence it is named Compact Galena. In colour and lustre it resembles common galena: it is not so easily frangible: and its fragments are not cubical, but indeterminately angular.

SECT. VIII.

OF ORES OF TIN.

TIN occurs in nature principally in the state of oxide, and in smaller quantity in that of sulphuret.

Native oxide of tin, or Tinstone, as it has been named by mineralogists, occurs massive, disseminated, in rounded pieces, and very frequently crystallized. The forms of

Its crystals are numerous, and they are often imperfectly marked. The principal are the octaedron, usually truncated on the common base of the two pyramids which compose it, sometimes bevelled on the edge of these bases, and often forming a twin crystal, by one being incorporated with another; and the rectangular tetraedral prism, acuminated by four planes, or by eight planes, both being farther modified by truncations of the edges or angles: these crystals are generally grouped. Its colour is brown, which is of various shades, passing into black, red, and more rarely into smoke grey, greenish, or yellowish white. Its lustre is shining, and, externally in the crystals, is highly splendid: when of a dark colour, it is opaque; when of a lighter shade, translucent, or semi-transparent: its fracture is uneven: it is hard and brittle: its specific gravity is from 6.300 to 6.989. It decrepitates before the blowpipe, and, when heated on charcoal, is reduced. The proportions of its parts vary little. A specimen from Cornwall, analysed by Klaproth, gave 77.5 of tin, 0.25 of iron, 21.5 of oxygen, and 0.75 of silic.

What has been named Wood Tin Ore, being an oxide of tin, may probably be regarded as a sub-species; though, as Klaproth discovered in it likewise iron and arsenic, it may perhaps form a species. It is found only in small rolled pieces or fragments. What distinguishes it more particularly from the preceding, is its distinctly fibrous fracture, whence its name has been derived. Its colour is brown: its lustre glistening: it is opaque, hard, brittle, and has a specific gravity of 6.456. It is not reduced before the blowpipe. By exposure to heat in a charcoal crucible, Klaproth obtained from 100 parts 73

of tin. It has been found only in Cornwall, in streams.

Tin mineralized by sulphur, in combination with copper and a little iron, forms what has been named Tin Pyrites. It occurs only massive or disseminated: its colour is steel-grey, passing into yellowish-grey: its lustre is metallic and shining, or glistening: it is opaque: its fracture is uneven: it is semi-hard, brittle, and has a specific gravity of 4.350. It exhales a sulphureous odour before the blowpipe, and melts without being reduced. Klaproth found it to be composed of 25 of sulphur, 34 of tin, 36 of copper, 2 of iron, with 2 of the earthy matter of the vein stone adhering to it.

SECT. IX.

OF ORES OF ZINC.

ZINC is mineralized by oxygen, carbonic acid, sulphuric acid, and sulphur.

One of its most abundant ores is that named Calamine. This occurs in various forms, sometimes earthy, or without much induration, sometimes more highly indurated, of a compact, or a striated texture, from which differences the species has been subdivided into varieties. It is massive, often cellular or corroded, or botryoidal, sometimes in minute crystals, forming a drusy incrustation: the forms of the crystals are the cube, the octaedron, the rectangular four-sided table, and the six-sided prism. Its colour is white, but often with various shades of yellow: it is dull, except when crystallized; the external sur-

face of the crystals being shining: the crystals are nearly semi-transparent: the variety, which is of a striated texture, is even when amorphous translucent; the earthy is opaque. In the highest state of induration, it is only semi-hard. Its specific gravity is from 3.5 to 4. It has the property, as Håüy discovered, of becoming electric by being heated. Calamine becomes white when heated before the blowpipe; in some specimens with decrepitation, but it is not reduced. Some varieties effervesce with acids; others do not: they dissolve in the nitric acid, forming frequently a solution of a gelatinous consistence. The composition varies considerably. Some varieties appear to be composed only of oxide of zinc and silex, with or without water. Thus, Klaproth found a variety, from Wanlock-head in Scotland, to consist of 66 of oxide of zinc, and 33 of silex; and Pelletier found a variety from Saxony, to be composed of oxide of zinc 36, silex 52, and water 12. More generally, however, carbonic acid is present, and then the silex is wanting. Bergman gave, as the proportions, 65 of oxide of zinc, 1 of oxide of iron, 28 of carbonic acid, and 6 of water. Mr Smithson more lately analysed several specimens, and found the proportions to be about 65 of oxide of zinc, and 35 of carbonic acid: in others water was present. Perhaps the calamine properly forms two species, the one a carbonate of zinc, the other an oxide of zinc with silex. It is the latter which forms a gelatinous solution with acids, and which becomes electric by heat.

Sulphate of zinc sometimes occurs with the sulphuret, probably formed from the oxygenation of the latter by the

action of air or water. It is tuberoso or stalactitic, of a greyish colour, and translucent; and is distinguished by its solubility in water, and its saline styptic taste.

Blende, or native sulphuret of zinc, presents several diversities in appearance. From difference of colour, three sub-species have been formed, the yellow, the brown, and the black; of which the brown is by far the most common. Its colour is brown, with shades of yellow and red, and often tarnished: its lustre is more or less splendent, and inclining to resinous; and it is more or less translucent: its fracture is foliated, sometimes fibrous: it is semi-hard, brittle, and has a specific gravity of from 3.7 to 4. It occurs massive, and disseminated, and often crystallized; the forms of its crystals being the three-sided pyramid, perfect or truncated on the angles; the octaedron, perfect or truncated on the edges or angles; the dodecaedron, and the four-sided prism acuminated by four planes: the crystals are also sometimes acicular. The yellow blende has a yellow colour of various shades, passing into green, or into red: its lustre is rather greater, and is adamantine; and when the colour is light, it is semi-transparent; it has the property of double refraction, and is phosphorescent from friction: its fracture is foliated. The black blende has a black colour, with a shade of brown or red: its lustre is metallic; its fracture foliated: it is opaque, or translucent on the edges.

Blende is scarcely ever a pure sulphuret, but, in addition to zinc and sulphur, contains generally iron, and often silex, argil, water, and sometimes lead, arsenic, silver, or copper. The yellow blende, according to Bergman's analysis, contains also fluoric acid. The brown

blende analysed by Bergman, gave the following composition,—zinc 44, iron 5, sulphur 17, silex 24, argil 5, water 5; the yellow blende, zinc 64, iron 5, sulphur 20, fluoric acid 4, silex 1, water 6; the black blende, zinc 45, iron 9, lead 6, arsenic 1, sulphur 29, silex 4, and water 6. The zinc in blende has generally been considered as in the metallic state, though to this is opposed the difficulty that zinc and sulphur cannot be combined together. Vauquelin affirms, that it is in the state of an oxide, and that blende is even sometimes a hydro-sulphuretted oxide *. Proust, however, has found by experiment, that it is merely a metallic sulphuret †.

SECT. X.

OF ORES OF NICKEL.

NICKEL occurs alloyed with arsenic, and a little sulphur; and in the state of oxide. The first species is the most abundant, and that from which nickel is usually extracted. It is known to mineralogists by the name of Kupper-nickel, or Copper-nickel, from its colour and appearance. It occurs generally massive and disseminated: its colour is copper-red, of various shades: its lustre is weakly shining and metallic: it is perfectly opaque: its fracture is uneven: it is hard, has no malleability, but is not easily broken: its specific gravity is from 6.6

* Nicholson's Journal, 4to, vol. v. p. 310.

† Ibid. 8vo, vol. xvii. p. 338.

to 7.5. Urged by the flame of the blowpipe, it gives vapours with a strong arsenical odour, and melts with difficulty. It dissolves in acids, giving a green solution. Bergman found it to be composed of nickel, iron, cobalt, arsenic, and sulphur. Vauquelin regards it as an alloy of nickel and arsenic, the others being accidental.

The other species, the oxide of nickel, occurs generally as an incrustation, sometimes also disseminated, of a friable texture and earthy appearance; of an apple-green colour, without lustre. It is not altered by the heat of the blowpipe, but, when mixed with borax, gives to it a yellowish-red colour. Its solution in acids is of a green colour. It occurs generally with kupfer-nickel, or with certain cobalt ores. It is also contained in small quantity in a fossil of the siliceous genus, chrysoprase, to which it communicates an apple-green colour.

SECT. XI.

OF THE ORES OF COBALT.

THIS metal occurs in nature, alloyed with some others, and likewise mineralized by oxygen, and by arsenic acid. Its ores are peculiarly distinguished by giving to borax, when fused with it by the blowpipe, a blue colour; and by forming, when dissolved in nitric acid, the sympathetic cobalt ink, which becomes green from heat.

The White Cobalt Ore, as it has been named, is an alloy of cobalt and arsenic, with a little sulphur, and in some specimens a little iron, the two latter being probably

accidental. One variety analysed by Klaproth, gave 44 of cobalt, 55.5 of arsenic, and 0.5 of sulphur. Its colour is tin-white, liable however to tarnish, and thus to assume a grey or reddish tinge: its lustre is weakly shining and metallic. It occurs massive and disseminated, of various imitative shapes, and crystallized in cubes, the angles and edges of which are sometimes truncated, and in octaedrons: the fracture is uneven: it is hard and brittle. Before the blowpipe it melts easily, and gives out an arsenical smoke and odour: it forms a metallic globe, and it gives to borax a blue colour.

To this species probably ought to be referred what has been named Shining Cobalt Ore, or Cobalt Glance. The differences between them, as Brochant has observed, are unimportant, and are probably owing to accidental intermixture: the colour, lustre, fracture, forms of crystallization, and the chemical characters, are the same. Some mineralogists have even supposed, that the next, the grey ore, ought to be connected with them, and the whole form one species. In the grey cobalt ore, however, iron appears to be essentially present, and communicates peculiar external and chemical characters, while the other two appear to be only an alloy of arsenic with cobalt.

The Grey Cobalt Ore, as it has been named, is an alloy of cobalt with arsenic and iron; sometimes also, with small portions of nickel and bismuth. Its colour is light grey, but very liable to tarnish: its lustre weakly shining and metallic. It occurs massive or disseminated: its fracture is even: it is semi-hard, passing into hard, brittle, and has a specific gravity of from 5.5 to 7.7. Exposed

to the flame of the blowpipe, it gives an arsenical odour, and smoke, but without melting : to borax it gives a blue colour, and is reduced to a metallic globule.

The native Oxide of Cobalt occurs in a loose form, or of various degrees of induration, but always dull, and earthy in its fracture, soft, and easily broken. It is also of different colours, from the intermixture of oxide of iron, and perhaps other metallic oxides ; whence even species have been formed and distinguished by the names of Black Cobalt Ochre, Brown Cobalt Ochre, and Yellow Cobalt Ochre. Of these the black appears to be the oxide of cobalt in its purest state. They all give a blue colour to glass or to borax when fused with it by the blowpipe. Sometimes also they exhale an arsenical odour.

The last species is that in which cobalt is mineralized by arsenic acid, the principal variety of which has been named Peach Bloom Cobalt Ore. This name it derives from its colour, which is a beautiful red, similar to that of the peach blossom, passing however into other shades of red, and from decomposition into other colours. It occurs massive, disseminated, and sometimes crystallized ; its crystals being acicular, or double six-sided pyramids, or rectangular four-sided prisms, and always very small : their lustre is shining : they are translucent : the fracture is radiated, the rays being sometimes straight, more commonly diverging. What is named the Earthy Peach Bloom Cobalt, has an earthy fracture, is without lustre, is soft and fusible, and occurs generally as an incrustation : before the blowpipe both varieties lose their colour, become grey, and give a weak arsenical odour : borax

receives a rich blue colour. This species has not been accurately analysed, but it is generally considered as an arseniate of cobalt.

SECT. XII.

OF ORES OF MANGANESE.

THE principal ore of manganese is the black oxide. There is another, the Red Ore, as it has been named, the nature of which does not appear to be well determined.

The first, the Native Oxide, presents different varieties with regard to colour, texture, and some other external properties, from the foreign substances occasionally combined in it. Its usual colour is steel-grey, inclining to brown or black, and varying in its lustre: when crystallized, the surface of the crystals is generally shining, which is not much changed in the streak; when amorphous, and especially when the fracture is earthy, it is more dull. Its texture is radiated, foliated, compact, or earthy. It occurs massive, disseminated, and crystallized: the forms of the radiated variety, are rhomboidal tetraedral prisms, modified by bevellment, or acumination by four planes on the extremities of the prism, or by truncation of the lateral planes: the foliated variety, when crystallized, is in rhombs: the compact and earthy are always amorphous. None of the varieties have much hardness: they are easily scratched by the knife, and often even soil when rubbed. The specific gravity varies from 3.5 to 4.7. All the varieties have the same general chemical cha-

racters. They are infusible when exposed to the flame of the blowpipe, but assume a brown colour. To borax they communicate by fusion a violet-blue colour. With sulphuric acid they yield oxygen gas, on the application of a moderate heat. Muriatic acid they convert into oxymuriatic acid. Their composition varies a little from accidental intermixture. The radiated variety appears to be a pure oxide; one specimen, analysed by Vauquelin, being composed of 92.75 of oxide of manganese, and 7 of water; another, of 99.25 of oxide, with 0.25 of water. But there are also frequently present small quantities of oxide of iron, carbonate of lime, silex, and barytes. The earthy variety appears to contain the largest proportion of oxide of iron.

What has been named Black Manganese Ore, a fossil extremely rare, has been described as a distinct species, but without any essential chemical difference being pointed out between it and the preceding varieties. Its colour is black, and reddish-brown in the streak; its fracture imperfect foliated: it occurs massive, disseminated, and in small octahedral crystals, aggregated in rows. The substance named Black Wad has been regarded as a variety of this: it occurs massive, or as an incrustation; is dull and earthy, of a dark steel-grey or blackish-brown colour. Mr Wedgwood found it to consist of 43 of oxide of manganese, and 43 of oxide of iron.

Oxide of manganese, probably in a less high state of oxidizement than the preceding species, combined with carbonic acid, has been considered as the basis of what is named Red Manganese Ore; though some have considered the carbonic acid as not essential, and have sup-

posed this ore to be a compound of oxide of manganese with silex. Its colour is rose-red, more or less pale, passing, from exposure to the air and light, to light yellow, or even to white. It has little lustre: occurs massive and disseminated; sometimes also, it is said, crystallized in rhombs or triedral pyramids. The fracture is even: its specific gravity is 3.233. Before the flame of the blow-pipe it does not melt, but acquires a dark grey colour: to borax it gives, by fusion, a violet tinge. According to Lampadius, this ore consists of 48 of oxide of manganese, 49.2 of carbonic acid, 2.1 of oxide of iron, and 0.9 of silex: according to Ruprecht, of 35.17 of oxide of manganese, 7.14 of iron, 58.06 of silex, 1.56 of argil, and 0.78 of water. It is scarcely possible that these two analyses can apply to the same species.

SECT. XIII.

OF ORES OF ARSENIC.

ARSENIC is found native, either nearly pure, or alloyed with some other metals, and combined with a little sulphur; and farther mineralized by sulphur, by oxygen, and in the state of acid with lime.

Native arsenic is of a white colour, with a slight shade of grey, with metallic lustre; but it tarnishes very quickly on exposure to the air, changing its colour, and losing much of its lustre. It occurs massive and disseminated: its fracture is uneven, sometimes approaching to foliated or striated: it is semi-hard, very brittle, and has a speci-

fic gravity of 5.6, or 5.7. It emits, when heated by the blowpipe, a white smoke having the arsenical odour, and burns with a blue flame. It generally contains a portion of iron, with sometimes a little silver or gold.

Arsenic alloyed with a much larger quantity of iron, and with a small proportion of sulphur, constitutes the species which has been named Arsenical Pyrites or Mispickel. Its colour is silver-white, but it quickly tarnishes, and becomes yellow, and sometimes iridescent : the lustre of its fresh fracture is shining and metallic. It occurs massive, disseminated, and often crystallized ; the forms of its crystals being the tetraedral prism perfect or bevelled on both extremities, and the octaedron very acute. Its fracture is uneven ; it is hard and brittle ; has a specific gravity of from 5.7 to 6.5. Before the blowpipe it exhales an arsenical vapour and odour : there remains an infusible scoria, consisting chiefly of oxide of iron. It contains very little sulphur, and, according to Bergman, from a half to two-thirds of its weight of iron.

What has been named Argentiferous Arsenical Pyrites, differs not much from the preceding species : its colour is silver-white, with a yellow tarnish, its lustre metallic, occurs generally disseminated, sometimes crystallized in slender rhomboidal tetraedral prisms. With arsenic and iron it contains a portion of silver, which varies from 1 to 10 hundredth parts.

Arsenic, mineralized by sulphur, forms two ores, named Orpiment and Realgar. That which has been named Realgar is of a red colour, sometimes inclining to scarlet, sometimes to orange. It occurs massive, disseminated, and crystallized in oblique tetraedral or hexaedral

prisms, generally small, and translucent, or semi-transparent, with a shining lustre. Its fracture is uneven : it is soft and brittle, and has a specific gravity of 3.2 or 3.3. It exhales before the blowpipe a white arsenical smoke, with an arsenical and sulphurous odour, and gives a blue flame. It consists of arsenic and sulphur, in the proportions, according to Westrumb, as stated by Kirwan, of 80 of the former, and 20 of the latter.

Orpiment is of a yellow colour, with a highly shining lustre, is translucent, or semi-transparent when in thin leaves. It occurs massive, and in very minute crystals. Its fracture is distinctly foliated : it is soft, capable of being cut, and somewhat flexible : its specific gravity is 3.3 or 3.4. It exhibits the same appearances before the blowpipe as the red sulphuret. It has been supposed to differ from the realgar, in containing a much larger proportion of sulphur ; the proportions, according to Westrumb, as stated by Kirwan, being 80 of sulphur, and 20 of arsenic. Others have supposed, that in both the arsenic may be oxidized, and that in the yellow the degree of oxidizement is greater than in the red. Thenard has lately made experiments on their composition, and has inferred, that neither of them contains oxygen ; they are both sulphurets ; the realgar containing the largest proportion of arsenic*.

Native oxide of arsenic occurs generally in the form of an incrustation on other ores, friable or little indurated, sometimes botryoidal, and even in minute crystals. Its colour is white, with shades of yellow or grey, dull and opaque ; when crystallized, translucent : its taste is

* Nichol森's Journal, vol. xix. p. 74.

acid, and it is soluble in water. Before the blowpipe it gives the arsenical odour.

Lastly, arsenic has been discovered in the state of an acid, united with lime, forming the ore which has been named Pharmacolite. This occurs as an incrustation, botryoidal, or in capillary crystals, of a white colour, with sometimes a shade of red, translucent on the edges, and with a silky lustre : its fracture is striated or fibrous : it is soft, so as to soil ; and light, the specific gravity being 2.5 or 2.6. It dissolves in nitric acid without effervescence, and gives the arsenical odour by the blowpipe. It contains, according to Klaproth's analysis, 23 of lime, 46.5 arsenic acid, 0.5 oxide of cobalt, 6 argil and silex, 22.5 water. It is found in a mine in Swabia, and, according to Brochant, likewise in France.

SECT. XIV.

OF ORES OF BISMUTH.

BISMUTH occurs native, mineralized by oxygen, and by sulphur.

Native bismuth has nearly the properties of the pure metal. Its colour is white, verging to red, and often tarnished ; with metallic lustre : its fracture is foliated. It occurs massive, more frequently disseminated, or superficial, sometimes crystallized, its crystals being four-sided tables, and cubes, generally small and indistinct. It melts very easily, a small fragment of it melting in the flame of

a candle. It is fused before the blowpipe, and, by continuing the heat, is oxidized and volatilized. It dissolves in nitric acid, and the solution is decomposed by water. It is the usual state in which bismuth occurs, being more abundant than either of the ores.

Oxide of bismuth appears generally as an incrustation, is sometimes disseminated, rarely massive. Its colour is yellowish-grey : its fracture earthy, sometimes uneven, or foliated : when earthy it is dull ; when foliated, shining. It is opaque, soft, and often friable. Heated on charcoal by the blowpipe, it gives a metallic globule, and it dissolves with slight effervescence in nitric acid.

Sulphuretted bismuth occurs massive, disseminated, and in capillary crystals : its colour is a very light grey : its internal lustre is shining and metallic : its fracture is foliated or striated : it is soft and brittle. It melts even in the flame of a candle. Heated by the blowpipe, it gives sulphureous fumes, and the metal being oxidized and volatilized, it leaves little residuum. According to Sage, it consists of 60 of bismuth, and 40 of sulphur.

SECT. XV.

OF ORES OF ANTIMONY.

THIS metal has been found native, combined with oxygen and with muriatic acid, and mineralized by sulphur.

Native antimony is a rare mineral : its external characters are nearly the same as those of metallic antimony. It occurs massive or disseminated. Exposed to the heat of the blowpipe it melts easily, gives a metallic globule, and exhales a white vapour that has a faint smell, somewhat similar to that of arsenic, which has been considered as indicating the presence of that metal, but which, according to Vauquelin, is a property of antimony itself in its oxidized state. Klaproth found it to consist of 98 of antimony, 1 of silver, and 0.25 of iron.

What has been named Antimonial Ochre, and which occurs generally as an earthy-like incrustation of a straw-yellow colour on the native sulphuret, has been regarded as an oxide of antimony, and probably originates in the decomposition of the sulphuret. It evaporates before the blowpipe in a white smoke.

What has received the name of White Antimonial Ore, appears to be likewise an oxide of antimony, though some chemists regard it as a muriate. It occurs generally in acicular crystals, grouped and divergent, so as to form a stellular appearance, sometimes in thin four-sided tables or in cubes : it is of a snow-white colour, with shades of grey or yellow, and a silky lustre, is translucent, soft,

and presents a foliated fracture. When heated before the blowpipe, it first decrepitates, then melts easily, giving a white smoke, and being even entirely dissipated if the heat be continued. The tabular variety from Bohemia had been suspected to be a muriate; and, according to Lampadius, it consists of 80 of oxide of antimony, and 20 of muriatic acid. From the analysis by Vauquelin, of the fibrous variety of it from Dauphiny, it appears, however, to be only an oxide of antimony; its composition, according to this analysis, being 86 oxide of antimony, 3 of oxides of antimony and iron, and 8 of silex. Klaproth has since examined the Bohemian variety, has found in it no traces of muriatic acid, and has concluded, that it is a pure oxide of antimony.

The principal Antimonial Ore, is that in which it is mineralized by sulphur, and which, from its fracture or appearance, has been sub-divided into four sub-species,—the striated, foliated, compact, and plumose Grey Antimonial ores. The first, that the texture of which is striated or radiated, is by far the most common. It occurs massive, disseminated, or often crystallized; its crystals being acicular, or four or six-sided prisms acuminate by four or six planes: they generally intersect each other, and are often aggregated, so as to form divergent groups. The colour is lead-grey, sometimes iridescent from tarnishing; the lustre shining and metallic. The specific gravity is from 2.4 to 4.5. The compact variety is distinguished principally by its fracture, which is small grained uneven. The distinction of the foliated is drawn from the same property; the fracture being foliated, passing sometimes into broad striated. The chemical characters of

these three sub-species are the same. They melt easily before the blowpipe, exhale a sulphureous odour, and emit a white smoke : if the heat be continued, the whole is dissipated, or at least there is only a small residuum of a white oxide. The species consists of antimony and sulphur, in the proportions, according to Bergman, of about 74 of antimony, and 26 of sulphur.

The plumose grey antimonial ore has been ranked as a sub-species of the preceding, but, from its chemical characters, is probably to be regarded as a separate species. It occurs generally in capillary crystals, aggregated, and usually superficial on other fossils, having less lustre than the preceding varieties, and less hardness. Heated before the blowpipe, it exhales a white vapour, and leaves a black scoria. It has not been accurately analysed ; but, according to Bergman, it is a sulphuret of antimony, with portions of arsenic and iron, and sometimes a little silver.

Antimony, mineralized by oxygen and sulphur, probably in the state of a sulphuretted oxide, constitutes what has been named Red Antimonial Ore, from its colour, which is a deep-red. It occurs generally in capillary crystals grouped ; opaque, and with an internal lustre shining and vitreous : its fracture is fibrous : its specific gravity from 3.7 to 4. It melts before the blowpipe, emits a sulphureous odour, and is gradually volatilized. From its resemblance in colour to an artificial combination of oxide of antimony with sulphuretted hydrogen, it has been supposed to be of similar composition,—a supposition improbable from the rare occurrence of sulphuretted hydrogen in the mineral kingdom, especially as an ingredient in a permanent combination. Klaproth's ana-

Analysis of it has shewn, that it consists of 67.5 of antimony, 10.8 of oxygen, and 19.7 of sulphur; the oxygen being probably combined with the metal, and the sulphur united with this oxide.

SECT. XVI.

OF ORES OF TELLURIUM.

TELLURIUM occurs principally alloyed with other metals, gold, silver, lead, and iron, and into the composition of some of these alloys, a small quantity of sulphur enters.

In nearly a pure state, or at least alloyed only with a small portion of gold and iron, it forms what was formerly known by the names of *Aurum Paradoxicum*, or *Aurum Problematicum*, as it appeared to contain gold, while very little could be extracted from it. It occurs massive, disseminated, and crystallized in tetraedral and hexaedral prisms, in triedral pyramids, in cubes, and in slender needles; is of a white colour, and has a shining and metallic lustre: its fracture is foliated: it is soft, and not very brittle: its specific gravity is from 5.7 to 6.1. It melts easily before the blowpipe, gives a dense white smoke, and a pungent odour: by continuing the heat it is oxidized, and at length melts into a glass. According to Klaproth's analysis, it consists of 92.55 of tellurium, 7.20 of iron, and 0.25 of gold. Sometimes, however, the gold amounts to even 9 in 100.

In what has been named the *Graphic Gold Ore*, the tellurium is alloyed with a large quantity of gold and sil-

ver; the proportions, according to Klaproth, being 69 of tellurium, with 30 of gold, and 10 of silver. It occurs crystallized in minute flat six-sided prisms, superficially aggregated on the surface of grey quartz, in such a manner as to give an appearance somewhat similar to written letters, whence the name. The colour is light steel-grey, the lustre shining and metallic, though somewhat liable to tarnish: the fracture is uneven: the specific gravity 5.7. It burns with a green flame before the blowpipe, and is volatilized. It is wrought as an ore of gold.

In the white or yellow sylvanite or tellurium ore, there is present a quantity of lead. The proportions, according to Klaproth, are tellurium 44.75, gold 26.75, lead 19.5, silver 8.5, and 0.5 of sulphur. Its colour is silver-white, inclining to yellow or grey; its lustre metallic: it is either disseminated, or crystallized in very minute tetrahedral prisms: it is soft: its fracture is foliated: its specific gravity is 10.678.

Lastly, in the black or foliated tellurium ore, there are associated a number of metals, with a little sulphur; the analysis of the ore, independent of the matrix, affording to Klaproth 82 of tellurium, 54 of lead, 9 of gold, 1.3 of copper, 0.5 of silver, and 3 of sulphur. Its colour is blackish-grey; its lustre shining and metallic: it occurs massive and crystallized in thin six-sided tables: its fracture is foliated: it is soft, so as to soil a little; is flexible in thin leaves, and has a specific gravity of 8.9. It melts before the blowpipe easily; is in part volatilized; and leaves a brown-coloured globule.

All these minerals have been found only in Transylvania.

SECT. XVII.

OF ORES OF CHROME.

THIS metal was originally discovered in the state of an acid in the red lead of Siberia. It has since been found combined with iron, and these two minerals are its only proper ores, though there are others in which it has been discovered in smaller quantity, particularly in some of the gems. It thus exists in the emerald in the state of green oxide, and in the spinel ruby in the state of acid.

The chromate of lead, or the red lead of Siberia, is generally crystallized in oblique tetraedral prisms. Its colour is a fine aurora red; its lustre shining, and intermediate between adamantine and resinous: the crystals are translucent: the fracture is uneven: the specific gravity 6.0269. It decrepitates before the blowpipe, and melts into a blackish scoria. It colours borax green by fusion. According to Vauquelin, it is composed of 57.10 of lead, 6.86 of oxygen, and 36.04 of chromic acid.

There is found with the chromate of lead, a mineral of a green colour in minute crystals, which Vauquelin found to be composed of the oxides of chrome and lead, and which, as he conjectures, has probably originated in the decomposition of the perfect chromate, from some process by which part of its oxygen has been abstracted.

Native chromate of iron has been found in the department of Var in France, and likewise in Siberia, and more lately in Styria. This mineral is massive, of a blackish brown colour, with no great lustre, and opaque: its frac-

ture is uneven, and it is hard, and difficult to break : its specific gravity is 4.0. It is scarcely fusible before the blowpipe, but with borax it melts into a glass of a fine green colour. According to the analysis of it by Vauquelin, it consists of oxide of chrome 43, oxide of iron 34.7, argil 20.3, and silex 2. Analyses of it have been likewise given by Klaproth and Laugier. That from Styria consists, according to Klaproth, of oxide of chrome 55.5, oxide of iron 33, argil 6, silex 2, volatile matter and loss 3.5. With this the analysis by Laugier of the Siberian variety very nearly corresponds. The discovery of chrome in bog iron ore by Vauquelin, has been already noticed.

SECT. XVIII.

OF ORES OF MOLYBDENA.

THERE is only one ore of molybdena admitted in mineralogical systems,—the sulphuret ; for although it exists also in the state of acid combined with lead, this is rather ranked as an ore of lead, and has accordingly been described as such.

The sulphuret of molybdena occurs usually massive or disseminated, but sometimes crystallized in hexaedral prisms, or hexaedral tables ; the crystals being small and imbedded. Its colour is lead-grey : its lustre is shining and metallic : its fracture is foliated : it is soft so as to soil, and to leave an impression on paper : it splits into leaves, which are somewhat flexible, and which cut easily ; feels unctuous : its specific gravity is from 4.0 to 4.7. It is

infusible before the blowpipe, but exhales a sulphureous vapour. Nitric acid does not dissolve it, but converts it into a white matter. Though Scheele supposed that the molybdena exists in this ore in the state of an acid, as it is in this state that it is extracted, yet there is reason to believe that the acid is formed by the processes employed, and that it is metallic molybdena that is combined with the sulphur. According to Pelletier, the proportions are 45 of molybdena, and 55 of sulphur; according to Klaproth, 60 of the former, and 40 of the latter. With the latter, the more recent analysis by Bucholz, exactly corresponds.

SECT. XIX.

OF ORES OF TUNGSTEN,

THERE are two species of tungsten ores,—one in which its oxide is united with lime, the other in which it is combined with oxides of manganese and iron.

The first of these, what has been named by mineralogists Tungsten, occurs massive or disseminated, sometimes crystallized in octaedrons. Its colour is yellowish or greyish-white, often tarnished: its internal lustre is shining and vitreous: it is translucent or semi-transparent: is soft: its fracture foliated; its specific gravity from 5 to 6. It does not melt before the blowpipe. Digested with nitric or muriatic acid, it gives a yellow powder, which is the oxide or acid of tungsten. According to D'Elhuyart, it consists of 68 of oxide of tungsten, and 30 of lime. Klaproth, in different specimens, found

the oxide of tungsten to amount to from 75 to 77 parts, with about 17 or 18 of lime, and small portions of silex, and oxides of iron and manganese.

The second species, Wolfram as it has been named, occurs massive, and likewise crystallized in broad hexædral prisms, or rectangular four-sided tables. Its colour is black : its lustre weakly shining : it is opaque : its fracture is distinctly foliated : its specific gravity from 6.8 to 7.1. Before the blowpipe it decrepitates, but does not melt. It appears to vary much in the proportions of its constituent parts. According to Vauquelin, it consists of 67 of oxide of tungsten, 18 of oxide of iron, 6.25 of oxide of manganese, 1.5 of silex, 7.25 of loss ; while in other specimens, the quantity of oxide of iron has been so high as 31, and that of oxide of manganese as 22 or 32.

SECT. XX.

OF ORES OF TITANIUM.

THE Ores of Titanium are more numerous than those of the greater number of the newly discovered metals, as the metal itself appears to be more abundant, and more widely distributed.

The Red Schorl, as it was named, the Titanite of Kirwan, the Rutile of Werner, appears, from Klaproth's analysis, to be a pure oxide of titanium. It is always crystallized, in prisms of four or six sides, frequently capillary, penetrating quartz : its colour is red, frequently with a shade of brown : its lustre is shining, and it is slightly translucent : it is hard and brittle : its fracture is foliated : its specific gravity 4.1. It is infusible before the blowpipe, but with borax forms a red transparent glass.

The fossil which has been named Rutilite, the Titanite of Klaproth, is either a variety of the Rutile, or perhaps a distinct species, as it contains, besides the metallic oxide, a considerable quantity of silex and lime. It occurs usually crystallized in rhomboidal four-sided prisms: the crystals externally are shining, internally glistening, the lustre being resinous; they are translucent on the edges, or opaque; their colour is reddish brown, but grey in the streak. specific gravity 3.5. The composition, according to Klaproth, is oxide of titanium 33, silex 35, lime 33.

What has been named Blue Schorl, and, from different mineralogists, has received the appellations of Oisanite, Anatase, and Octahedrite, appeared, from the analysis of it by Vauquelin, to be oxide of titanium with silex. It occurs always crystallized in very acute octaedrons: its colour is blue, of various shades, passing sometimes to brown: its lustre is shining and adamantine: it is translucent or semi-transparent: its fracture is foliated: its specific gravity is 3.8. It does not melt before the blow-pipe alone, but with borax forms a glass of a reddish-brown colour, which, by urging the flame, becomes blue, and at length white; and at a still higher heat, the reddish-brown colour returns. From a later examination of it, Vauquelin infers that it is oxide of titanium nearly pure, and that it differs from rutile in being free from iron.

The Menachanite of Cornwall is in the state of small angular grains, or sand, of a greyish black colour, with a semi-metallic lustre, and perfectly opaque, having a specific gravity of 4.4, and weakly attracted by the magnet. It is infusible before the blowpipe, but gives to borax a greenish colour. According to Klaproth's analysis, it

consists of oxide of iron 51, oxide of titanium 45.25, oxide of manganese 0.25, and silice 3.50. A variety from Botany Bay, was found by Mr Chenevix to contain rather more silice.

What has been named Nigrine, occurs likewise in angular grains, of a brownish-black colour: its lustre is weakly shining, and it is quite opaque: its specific gravity is 4.5; it is not attracted by the magnet; is infusible before the blowpipe, but, with borax, melts into a hyacinthine glass. It consists, according to Klaproth, of 84 of oxide of titanium, 14 of oxide of iron, and 2 of oxide of manganese.

Iserine, as it has been named, occurs, like the two preceding fossils, in angular grains; its colour is iron black; its lustre weakly shining and metallic; it is completely opaque; is hard and brittle; and has a specific gravity of 4.5. It melts before the blowpipe into a dark brown glass, which is slightly attracted by the magnet. It consists of oxide of titanium 59.1, oxide of iron 30.1, and oxide of uranium 10.2. These three last fossils are probably gradations of one species.

SECT. XXI.

OF ORES OF URANIUM.

KLAPROTH, who first discovered this metal by his analysis of its ore, named Pechblende, found that it existed besides in other two minerals; and these three form the species of this genus.

The first of them, the Pechblende, or sulphuretted ura-

nite, occurs generally massive, of a black colour, having an internal lustre shining and resinous, and quite opaque : its fracture is imperfect conchoidal ; it is brittle and soft, and has a specific gravity of 7.5. It is infusible by the flame of the blowpipe, but with borax it produces an opaque grey glass. It dissolves in nitric acid, leaving a little sulphur undissolved. According to Klaproth, it consists of 86.5 of oxide of uranium, 6 of sulphuret of lead, 5 of silex, and 2.5 of oxide of iron.

The Green Mica, or micaceous uranitic ore, appears to be an oxide of uranium, nearly pure, or mixed only with a little copper. It occurs in thin leaves, or crystallized in minute four-sided tables ; its colour is green ; its lustre is shining ; it is more or less translucent ; its fracture is foliated ; it is soft, and easily broken ; has a specific gravity of 3.1. It is dissolved by nitric acid, forming a solution of a lemon-yellow colour.

What has been named the Uranitic Ochre, occurs generally as an incrustation or efflorescence, sometimes massive ; its colour is straw-yellow, which sometimes acquires a tinge of green, brown, or red ; it has no lustre ; is opaque ; generally soft and friable ; has an earthy fracture, and feels meagre : its specific gravity is 3.2. According to Klaproth, it is oxide of uranium nearly pure, containing, when of a red or green colour, only a little oxide of iron.

SECT. XXII.

OF ORES OF COLUMBIUM.

IN the history of this metal it was stated, that only one ore of it is known to exist; and with regard even to its locality, nothing certain is known: nor can any description of it be given but that which Mr Hatchet gave of the specimen he analysed. It is massive; of a dark brownish-grey colour; its lustre is shining, and inclining to metallic; its fracture is imperfectly foliated, is moderately hard, and very brittle; its specific gravity is 5.918; its particles are not attracted by the magnet; and acids act very weakly upon it. It consists, according to Mr Hatchet's analysis, of a metallic acid, of which columbium is the base, 78 parts, and oxide of iron 21.

SECT. XXIII.

OF ORES OF TANTALIUM.

THE newly-discovered metal Tantalium was extracted from two minerals which have been named Tantalite and Yttrotantalite, and which form its only known ores.

Tantalite is an alloy of it with iron and manganese. It occurs in imperfect crystals of an octaedral form, of a black colour, with an internal metallic lustre: its fracture is compact; it is so hard as to give sparks with steel; its specific gravity is 7.953.

Yttrotantalite is found in small masses imbedded in feldspar; its colour is iron black, with metallic lustre; its fracture is granulated, and it is scratched by the knife; its specific gravity is 5.130. It consists of tantalium with iron, and a portion of the lately discovered earth, Ittria.

SECT. XXIV.

OF ORES OF CERIUM.

THE only known ore of this metal is that in which it was discovered, the mineral found at Bastnaës in Sweden, which had been named False Tungsten. To this ore, the Swedish chemists, the discoverers of the metal, have given the name of Cerite.

It occurs disseminated or massive, is of a flesh-red colour, more or less deep, with sometimes a shade of yellow: it is semi-transparent: its fresh fracture has considerable lustre: it strikes fire with steel with difficulty: is not attracted by the magnet: its specific gravity is from 4.7 to 4.9. Exposed to a strong heat, it does not melt, but loses 5 or 6 *per cent.* of weight, becomes friable, and acquires a bright yellow colour. With borax, it forms a globule, greenish while hot, but colourless when cold. From 100 parts of it, the Swedish chemists obtained about 50 of oxide of cerium, 22 oxide of iron, 23 silex, and 5.5 carbonate of lime. According to Vauquelin's analysis, the proportions are oxide of cerium 63, silex 17.5, oxide of iron 2, lime from 3 to 4, water 12.

CHAP. IV.

OF INFLAMMABLE MINERALS.

THE minerals under this order are connected entirely by the chemical property of Inflammability: in their external characters, they are extremely different from each other. These minerals may perhaps be arranged, according to their chemical relations, under three genera. Sulphur may be placed under the first. To the second may be referred those in which Carbon is the chief ingredient, including the Diamond, the purest form under which this principle is presented to us, Plumbago or Graphite, and the different varieties of Coal. With coal, the soft, and even the liquid bitumens, have been usually associated, and there is no doubt a series which connects them. But such transitions are not uncommon in the sub-divisions of the mineral kingdom, where the substances, at each extremity of the series, are still extremely different, and form even distinct genera. In the liquid bitumens, hydrogen, rather than carbon, appears to be the predominating ingredient, communicating to them their lightness and volatility. They may therefore form a genus under which may be placed naphtha, mineral tar, and the substances most nearly connected with these. Amber, which in its original state appears to have been liquid, may likewise be referred to it, as may also, perhaps, the mellite, or honey-stone. And under these three genera, we shall have all the inflammables, not metallic, of the mineral kingdom.

SECT. I.

OF NATIVE SULPHUR.

SULPHUR occurs in the mineral kingdom under different forms, and is evidently of various origin. Much of it is a volcanic production, but it is also found imbedded in various strata, particularly in gypsum and limestone; and sometimes, though in smaller quantity, in veins which traverse primary rocks. It is nearly or perfectly pure, of its characteristic yellow colour, semi-transparent, or sometimes transparent, when it possesses, as Haiiy has remarked, the property of double refraction; its lustre is shining: it is soft and brittle: it occurs massive, disseminated, or crystallized. The form of its crystals is the octohedron or double tetrahedral pyramid joined obliquely at the bases, modified not unfrequently by truncations of its summits, of the edges of the common base, or of the angles of the base: sometimes, also, its form is that of the double six-sided pyramid: the surface of the crystals is smooth and shining, and their size is very various. This description applies to sulphur not volcanic. Sulphur, having this origin, occurs corroded, vesicular, in masses, and as a light sublimate; is of a yellow colour, inclining to green, and slightly translucent. It is found at Vesuvius, Etna, the Lipari islands, Iceland, and some of the West India islands. Sulphur, not of a volcanic origin, is met with in many of the countries of Europe, Spain, Poland, Switzerland, France, Italy, and Sicily, as well as in Asia and America.

SECT. II.

OF CARBONACEOUS MINERALS.

OF these the Diamond is the purest. It consists, indeed, of carbon nearly pure, or, according to Mr Davy, combined only with a little oxygen. From its external characters, it has been placed among the earthy fossils; and were there any doubt with regard to its nature, such a provisional arrangement might be allowed. But no such doubt can be entertained; and in a system professing at all to admit of the chemical relations of bodies into the principles of the arrangement, it is obviously too great a departure from these principles, to place an inflammable substance with others altogether unflammable, and with which it has not the slightest connection in constitution. Nor does it form any valid objection to arranging it with the other carbonaceous fossils, that it differs greatly from them in external characters, for as great differences exist among the substances arranged under many of the other genera of the mineral kingdom; as for example, between the different ores of one metallic genus, or between the different fossils which are connected by their relation to one earth.

The DIAMOND is found in India, in the districts of Visapour and Golconda, and likewise in Bengal, and in Brazil in South America. It is not met with in its original situation, but in the beds of streams, or in a loose ferruginous sand beneath the soil. The Brazilian diamonds are inferior in transparency and purity to the Oriental.

The diamond is found crystallized, being either in per-

fect crystals, or in fragments often encrusted with a hard coating. The usual form is an octohedron, composed of two four-sided pyramids joined by the base, the faces being somewhat convex. Of this form, there are some modifications; the angles being replaced by triangular faces, so as to give rise to a dodecahedron of 24 planes, likewise a little convex. These are the crystallizations of the Oriental diamond. The Brazilian is generally in a dodecahedron with rhomboidal planes. These crystalline forms are often imperfect, probably from the attrition which they have suffered, and frequently the fragments are altogether indistinct.

The diamond is colourless, or tinged of various shades of white or grey, and sometimes also, though more rarely, of brown, green, yellow, blue, and red, frequently with darker coloured spots; it is generally transparent, though not perfectly so, and has the property of single refraction; its fracture is lamellated, and it can be split by striking it in the direction of the plates. Its specific gravity is from 3500 to 3600.

PLUMBAGO, or GRAPHITE, Black Lead as it is sometimes named, it has already been remarked under the history of carbon, and also under that of iron, is a carburet of iron. The proportion of this metal, however, in its composition, is very various; on an average it does not exceed 1 part in 10, and is sometimes less. Graphite occurs massive, or disseminated; its colour is black, or dark steel-grey; its lustre is weakly shining and metallic; it is opaque; its fracture is either compact or foliated, or slaty; it is soft, soils the fingers, and feels unctuous; its specific gravity is from 2.1 to 2.6. It burns with great

difficulty, and consumes very slowly, affording carbonic acid, and leaving oxide of iron as a residuum, frequently mixed with considerable quantities of argil and silex.

Graphite, though not a very abundant mineral production, is found in different countries. It is procured of a very fine quality from Borrodale in Cumberland. It appears generally to occur in beds, or in imbedded masses, in primary rocks, or rocks of transition; sometimes, also, connected with what is named the Independent coal formation. Its chemical history has been already given.

COAL consists essentially of carbonaceous matter, and in one variety, the blind coal, or Mineral Carbon as it has been named, this is nearly pure; but in the greater number of the varieties of coal, there is associated with this a soft bituminous matter, or at least such a bitumen can be extracted from them by heat; and its presence communicates to them some peculiar properties. Those which contain much bitumen are highly inflammable, take fire readily, and burn with a bright flame: those in which the proportion of bitumen is less, and in which the carbon predominates, burn less vividly; they require a higher heat to kindle them, and burn without flame, or only with a red glow. During the combustion, the products are principally water, and carbonic acid gas; sulphurous acid is also formed in small quantity, derived probably principally from the sulphuret of iron contained in the coal; and a portion of ammonia, the origin of which is not very obvious, appears also to be formed, as sulphate of ammonia is always contained in the soot collected from the combustion of coal. The earthy matter which is likewise contained in coal, remains after the combustion, and is seldom in large proportion.

The bituminous part of coal is separated from the carbonaceous part by the application of heat. We perceive this separation in its combustion in a common fire; the coal, when first kindled, swelling and softening, exhaling a kind of bitumen, and burning with much smoke and light; while, after a certain period, these appearances cease, and the coal burns only with a red light. The separation is effected more completely by the application of heat in close vessels: the bitumen is melted out; there is disengaged at the same time a large quantity of ammonia, partly in the state of carbonate with a quantity of empyreumatic oil, and a gas, a variety of oxy-carburetted hydrogen, approaching in its nature to olefiant gas, which burns with a bright flame. When this species of distillation is continued until these products are no longer formed, the carbonaceous matter of the coal remains in the state of coak, which, if the air be admitted and the temperature sufficiently high, burns without flame.

This decomposition of coal by heat has been carried on on a large scale, with a view to collect the products; the bituminous matter, or mineral tar as it is named, being applied to the uses for which vegetable tar and pitch are employed, and the coaked coal being used with advantage in the smelting of metallic ores, and for other purposes. The process was established in this country by Lord Dundonald, and has also been carried on with advantage in other countries. More lately the distillation of coal has been applied to the procuring an elastic fluid, to afford by its combustion artificial light. The coal is put into an iron bottle or retort, which is placed on a common fire, or, what is preferable, in a furnace. The

retort or bottle is connected by a wide tube, with a vessel constructed on the principle of the gas-holder, containing water; and the gas expelled from the coal by the application of the heat, is conveyed through the water, by which a great part of the oily matter adhering to it, that would clog the smaller pipes at the extremity of which the gas burns, and would also give an unpleasant odour, is removed. From this vessel or reservoir, which is of course of a size proportioned to the extent of the apartment to be lighted, pipes issue which convey the gas to any distance, and which subdividing, terminate in branches with small apertures, at which the gas, as it passes out, being kindled, burns; and these being furnished with stop-cocks, the combustion can be regulated with great precision. From the account given by Mr Murdoch of this application of the coal gas on a large scale *, it appears to be extremely advantageous; being much more economical than any other mode, and affording a more speedy, uniform, and easily regulated light; the advantages of economy, of course, being greater, the larger the scale is on which it is conducted. Even on a smaller scale, it appears, from some observations by Mr Cook, to be preferable to any other mode †; though it will probably never be established in private use, from the attention the process requires. Mr Nicholson has also very justly observed, that the advantages from it, even on a large scale, must be considerably dependent on local situation, particularly with regard to the cheapness of coal, and the demand for coak ‡.

* Philosophical Transactions, 1808.

† Nicholson's Journal, vol. xxi. p. 291. ‡ Ibid. 101.

The general chemical history of coal is almost entirely confined to these facts, as the action of other substances upon it has been little attended to, and does not appear indeed to be very energetic. Mr Hatchet has found, that, when treated with nitric acid, it affords artificial tannin; and those varieties of it which contain bitumen, yield, at the same time, by this treatment, a matter intermediate in its characters between extract and resin, and which, by the farther action of nitric acid, is converted into tannin*.

Numerous varieties of coal exist, deriving their distinctions as objects of mineralogical description, partly from their state of aggregation, but principally from the proportions of their bitumen and carbon. As subjects of chemical history, these latter distinctions are of course those which are chiefly to be attended to. The series may be briefly described, according as they are connected, on the one hand, with vegetable matter, and, on the other, with carbon, evidently not of vegetable origin.

BLIND COAL, the Anthracite of mineralogists, the Glance coal of Werner, consists almost entirely of carbon, and hence forms the connection of Coal with Plumbago. It burns without flame, without exhaling any bituminous odour, and without softening or caking; nor does it continue to burn of itself until it is fully ignited, and then burns slowly. It constitutes this transition not only in its chemical relations, but also in its external properties. Its colour is usually black, sometimes incining to steel-grey; its lustre is shining, and nearly metallic: its fracture is slaty; its hardness such as to yield easily to the knife; it is brittle, and has a specific gravity of about 1.5. It

* Philosophical Transactions, 1806.

occurs generally in primitive rocks, or in those of transition in imbedded masses, in beds and veins. It has also been discovered by Mr Jameson in the independent coal formation in the island of Arran, and is not therefore exclusively of an early formation, as had been supposed. There appears no reason to infer that it is of vegetable origin. Brochant gives the following analysis of it, executed by Panzenberg and Dolomieu: that of the latter, there is reason to suspect, however, refers rather to a variety of graphite.

	Panzenberg.	Dolomieu.
Pure carbon	90	72.05
Silex	from 4 to 2	13.19
Argil	— 4 to 5	3.29
Oxide of iron	— 2 to 3	3.47
Loss	————	8.00

What has been named by Werner **BLACK COAL**, the species which is by far the most abundant, is subdivided into several varieties from slight differences in properties. That named Pitch coal, from its resinous lustre and smooth conchoidal fracture, forms the variety which has been known under the name of Jet, and which, from the closeness of its texture, is capable of being fabricated into ornaments. Its colour is deep-black, and the ligneous texture is often to be perceived in it. It burns with flame, and a bituminous smell not unpleasant. Cannel coal, so named from affording much light in its combustion, has, like the preceding, a smooth conchoidal fracture, a resinous lustre, and a black colour, and is sometimes applied to similar uses, though used also abundantly as fuel. It burns without melting; its light is at first bright, but

soon ceases, and it then leaves a large coally residuum. It contains, according to Mr Kirwan's analysis, 75.2 of carbon, 21.68 of bitumen, and 3.1 of foreign matter. The Slaty coal forms the variety most abundant in this country ; its principal fracture is slaty, the cross fracture small grained uneven ; its colour is black, frequently with a shade of grey, and sometimes iridescent ; its lustre resinous ; it is soft, and has a specific gravity of about 1.25. It softens, cakes, and burns brightly, and leaves, when entirely burnt, a small residuum of ashes. It appears, therefore, to contain more bitumen than the preceding varieties ; the proportion in different kinds appears, from Mr Kirwan's analysis, to vary from 24 to 40, with from 53 to 70 of carbon, and 2 or 3 of earthy matter. The Foliated coal, as it has been called, approaches to the slaty, being distinguished by its fracture and its greater lustre : it is also softer, and appears to contain more bitumen. Columnar coal is so named from occurring in columnar distinct concretions, and is more rare. It burns without flame or smell, and hence is probably connected with the preceding species, or Blend Coal.

BROWN COAL occurs massive, having an imperfect conchoidal fracture, sometimes fibrous and woody, soft and light, which burns with a blue flame, and gives a smell like bituminous wood, it occurs with some of the following varieties, in alluvial land. Mr Hatchet found a coal of this description to afford by distillation, besides a portion of water slightly acidulous, amounting to 30 parts from 100, bitumen in the proportion of only 10.5, charcoal 45, and carbonic acid and carburetted hydrogen gases 14.5. Connected with this species, are what have been named Earthy Bituminous Wood, or Earthy Coal, which is found of a

loose consistence, nearly earthy, dull, of a blackish-brown colour, light and soft ; which occurs along with the bituminated wood, and passes into it. Some of these earthy varieties are used as paints ; umber is one of them : and some of them which contain much earth and sulphuret of iron are wrought for the manufacture of alum.

The last of the series, or that most evidently of vegetable origin, is what has been named Bituminous Wood, from the ligneous texture remaining. This texture is very distinctly marked, and even the external shape of the branches and stems of trees, and the annual rings of the wood, are distinctly preserved, so as to resemble wood imperfectly charred. Its colour is brown, of different shades : it is opaque, with little lustre, has little density or hardness, and is so light as nearly to float on water. It burns with a clear flame, and with a bituminous odour, somewhat similar to that from wood ; and it leaves a small quantity of white ashes, similar to those from wood. It is found in beds, generally in alluvial land, and in masses with other varieties of coal, or imbedded in rocks of the trap formation. The Bovey Coal, near Exeter, is an example of it, as is also the Surturbrand of Iceland.

The following table gives the results of an analysis of different coals by Mr Kirwan, made by projecting a certain quantity of each on ignited nitre, observing how much nitre was decomposed or alkalized, and inferring from this what proportions of bitumen and carbon they contained, the carbon only being supposed to exert this operation. This assumption is perhaps not just, and several sources of fallacy attended the experiment. The last five coals in the table appear to be varieties of black slaty coal. The Kilkenny is a variety of Blind Coal.

100 parts	Carbon.	Bitumen.	Ashes.
Maltha	8	—	—
Asphalt	31	68	—
Kilkenny coal	97.3	—	3.7
Compact cannel—	75.2	21.68	3.1
Slaty cannel—	47.62	32.52	20
Whitehaven—	57	41.3	1.7
Wigan—	61.73	36.7	1.57
Swansey—	73.53	23.14	3.33
Leitrim—	71.43	23.37	5.20
Newcastle—	58	40	—

Coal, excluding the anthracite or blind coal, is evidently of vegetable origin. We trace in it, as has been already remarked, the gradation from bituminated wood; we often discover in its varieties the ligneous structure, and even the remains of plants; and its chemical composition agrees with that of vegetable matter.

It is difficult, however, to determine in what manner it has been formed, or by what operations the vegetable matter from which it is originated has been so far modified as to have assumed the properties under which it exists. The discussion of this subject is indeed intimately connected with geological speculation; for the opinion which is adopted must be connected with the general theory which is held with regard to the structure of the globe. In the geological systems of the present day, very different opinions are accordingly maintained with regard

to the origin of coal : in the system of Werner, it is regarded as originating from vegetable matter, altered by operations conducted in the humid way : in the system of Hutton, it is supposed to have been formed by the action of subterranean heat, operating under partial compression.

Were the latter system received, and the theorist allowed the convenient assumption, that wherever coal had been formed, a *partial* compression had existed, the experiments of Sir James Hall have rendered it probable, that from such a cause a substance might be produced somewhat analogous to coal ; as by a very moderate heat, applied under such compression both to vegetable and animal substances, as saw-dust and horn, he formed matter more or less bituminous *.

On the supposition that it is of aqueous formation, the process from which it may have originated may be conceived to be somewhat similar to that in which vegetable matter in a state of humidity, and under compression, suffers decomposition from the re-action of its elements, these circumstances determining the combination of its oxygen principally with its hydrogen, so as to leave the carbon predominant. It may be supposed, “ that vegetable matter carried to the sea, has, by the direction of currents, been deposited in banks, and that during this submersion it has suffered that slow kind of decomposition by which the greater part of its principles have been evolved in new combinations, while its carbon, with a portion of hydrogen, have remained ; and this, mixed with more or less

* Transactions of the Royal Society of Edinburgh, 1805.

earthy matter deposited at the same time from the ocean, has in its soft state been consolidated by the force of aggregation, and has formed coal. The decomposition by which this has been effected, is probably analogous to that which we know animal matter, when immersed in water, suffers. Its hydrogen, azot, and oxygen, enter into various combinations, forming gases which escape; and its carbon, retaining, by a chemical attraction, a portion of hydrogen in combination, remains, forming a species of fat. Carbon is still more abundant in vegetable than it is in animal matter; and this constitutes the principal difference between them. Vegetable matter, however, is liable to similar decompositions; and under the circumstances pointed out, it is reasonable to believe that changes of a similar kind, modified as to the result by the difference in the proportions of its principles, will take place: in other words, its residue will be more carbonaceous, but still with a proportion of hydrogen, so as to render it more or less bituminous. We accordingly find, that wood, by immersion in water, becomes first brown, and then black; and the ligneous fibre, by slow decomposition, is completely converted into a black mould, in which carbon predominates. It is easily conceivable, that this process, being carried on under different circumstances, may proceed with various degrees of rapidity, and to a greater or less extent. Hence will originate different varieties of coal, some being much more carbonaceous than others, while their composition is also varied by the different quantities of earth deposited during their formation *."

* Comparative View of the Huttonian and Neptunian Systems of Geology, p. 208.

Mr Hatchet has remarked, that observations on the state of wood, in submarine forests, demonstrate, that whether vegetables are totally or partially buried under the waves, or under the earth, they are not merely by such means converted even into the most imperfect sort of coal, and that therefore some process independent of these circumstances must have taken place in the formation of this substance. And having found, that from the action of acids on vegetable matter, products might be obtained more or less similar to bitumens, he has supposed that some such action, exerted by muriatic, or more probably sulphuric acid, may have contributed to the formation of coal*. It is not easy, however, to conceive how these could operate on collections of vegetable matter on the large scale, that must be supposed to account for the formation of strata of coal; and the consideration that wood is found long submersed without having been bituminated, perhaps only proves that the process is extremely slow, not that the changes which it actually does suffer might not ultimately pass to that state.

SECT. III.

OF INFLAMMABLE MINERALS IN WHICH HYDROGEN PREDOMINATES.

UNDER this genus may be more particularly placed the liquid bitumens; which are all of them more or less light, volatile, and highly inflammable.

NAPHTHA appears to be the purest. It is very light, of

* Philosophical Transactions, 1806.

a pale yellow green colour, more or less transparent, thin and liquid, light, so as to float on water, odoriferous, volatile, and inflammable, and in burning is entirely consumed, emitting a smoke more or less dense. It flows generally from crevices in rocks.

PETROLEUM, or Mineral Tar, is semi-liquid, often of a thicker consistence, tenacious, semi-transparent, of a reddish-brown colour, and foetid odour.

MINERAL PITCH, or Maltha, is solid, but soft, has a degree of tenacity, and a strong bituminous smell. Its colour is black, its lustre highly resinous. It is sometimes elastic, forming what has been named the Elastic Bitumen. A variety of this found in a vein of a lead-mine near Castleton was examined by Mr Hatchet, who found it had all the properties of these bitumens, and who supposed, that it owed its elasticity to minute portions of air interspersed in its substance; as, when melted, it completely lost the elastic property, and, at the same time, gave out a quantity of aërial fluid. This might, however, be only an accidental coincidence; and Mr Hatchet having since found, that there is a strict resemblance between the elastic bitumen and caoutchouc, in the changes they suffer from acids *, it is not improbable that the property may depend on some peculiarity of combination.

ASPHALTUM is the last of the series, and forms the connection with pitch coal. It is of a black colour, and resinous lustre, without transparency: its fracture is conchoidal: it feels somewhat greasy; is light, and has a bituminous smell, when rubbed or heated. It melts easi-

* Philosophical Transactions, 1806.

ly, takes fire, and burns without leaving any ashes. It is found in veins, and in small masses, and also sometimes on the surface of lakes.

Through all these substances there is a perfect gradation; naphtha, by inspissation, becoming petroleum, and this, by the same operation, passing into asphaltum; and even the different specimens of these are frequently found in the same situation. These changes, as Mr Hatchet in his paper on bitumens remarks*, appear to be caused by the gradual dissipation of part of the hydrogen of the bitumen, and the consequent developement of a portion of carbon. They also agree in their chemical characters, are inflammable, insoluble in water and in alkohol, but combine with fixed and essential oils, and are partially soluble in ether. They are not dissolved by the alkalis; are decomposed by the more powerful acids, especially by the nitric, which, as Mr Hatchet found, causes the production of a substance intermediate in its properties between extract and resin, and which, by the farther action of the acid, is converted into tanmin.

There is some obscurity with regard to the natural sources of these bitumens. Those that are liquid are found generally exuding from crevices in the rocks which accompany coal, and frequently flow on the surface of water which has probably run over coal strata.

AMBER is usually placed among the bitumens, though it differs from them considerably in its properties. It is of a yellow colour, pale or deep; is often perfectly transparent, and has a shining lustre; at other times it is more

* Nicholson's Journal, 4to, vol. i. p. 201.

or less opaque : its internal lustre is highly shining : it is inodorous, unless when heated, and is insipid : its fracture is conchoidal : it is brittle, and has a specific gravity of about 1.08. When rubbed, it becomes strongly electrical : it was in this substance that this property was first observed ; and it is from the name under which it was known to the ancients, *Electrum*, that the term Electricity has been derived.

Amber occurs in fragments, or sometimes in large masses : it is found in layers of bituminated wood, often, also, buried in sand on the sea-shore. No very satisfactory theory has been given of its origin or formation. It often contains very perfect organic remains, especially insects, and sometimes leaves of vegetables,—a proof of its having been once perfectly fluid. It is found in greatest quantity on the shores of the Baltic, but occurs also in other countries.

With regard to chemical properties, amber approaches to the resins, which are vegetable compounds, in the composition of which hydrogen appears to predominate, but it presents also some peculiarities, especially in affording an acid *sui generis*, when decomposed by heat.

When it is exposed to heat in close vessels, it softens and swells ; a quantity of an acidulous liquor passes over ; this is succeeded by a concrete acid, which condenses in flakes or needles ; a considerable quantity of an oil highly empyreumatic, and of a deep brown colour, also distils ; a black resinous-like substance forms the residuum.

When amber is heated in contact with the air, it inflames, burns with much smoke, and with a strong bituminous smell, and leaves little residue.

Water exerts no action on amber. Alcohol acts on it weakly, acquires colour and some tenacity from a portion being dissolved.

Hoffman observed, that amber reduced to powder, and boiled in a solution of pure potassa, is almost entirely dissolved. It combines with the alkalis, and forms a kind of soap, and, in this respect, has therefore a near resemblance to the resins.

Amber is decomposed by the more powerful acids, which change it into a species of resin. Mr Hatchet found it yields abundance of artificial tannin, when subjected to the action of sulphuric acid, in the same manner as the resins and balsams.

There is one property in which it differs from the resins, that of not being dissolved either by the expressed or essential oils ; but it becomes soluble by being roasted gently. Solutions of this kind are used as varnishes. This varnish is preferable to almost any other for a number of purposes. It dries speedily : it does not crack, and is extremely durable. In mixing with colours, it is also said to render them more brilliant, and preserve them better than the drying oils do. There is some difficulty, however, in preparing it, principally with regard to the heat to be applied. Ample directions have been given, in a dissertation on this subject by Nils Nyström *.

The empyreumatic oil obtained from the decomposition of amber by heat is thick, and of a dark colour : by distilling it repeatedly, with the addition of a little water, it becomes thinner, and of a lighter colour, leaving

* Philosophical Magazine, vol. vii. p. 233.

at each distillation a little coally matter : and at length it may be obtained nearly colourless. It still retains a very fætid smell : it is volatile and inflammable ; is soluble in water, and imperfectly soluble in alkohol. It also combines imperfectly with the alkalis. Liquid ammonia impregnated with it forms Eau de Luce. Concentrated sulphuric acid poured upon it produces considerable heat, and converts it into a yellow resin, having a fragrant odour, somewhat similar to that of musk.

The acid obtained by the same decomposition, the Succinic Acid as it is named, is possessed of properties which sufficiently distinguish it. As first procured, a portion of empyreumatic oil adheres to it, and gives it colour and smell. From this it is not perfectly freed, even by repeated solution and crystallization. If charcoal powder recently prepared be added to its solution in water, and the solution be made to filtre through the charcoal, it is obtained more pure, as it is also, according to Guyton, by distilling a little nitric acid from it ; or, according to a process given by Richter, it may be combined with potassa : the salt thus formed may be decomposed by acetate of lead ; and the succinate of lead may, lastly, be decomposed by sulphuric acid.

This acid crystallizes in four-sided rhomboidal plates, which, when pure, are white ; their taste is sour, and they redden infusion of litmus ; they are rather sparingly soluble in cold water, requiring twenty-four parts for their solution, but are abundantly soluble in hot water ; they are also soluble in alkohol. This acid is also volatile and inflammable. In these properties it bears some resemblance to benzoic acid. Like the vegetable acids,

it has a compound base of carbon and hydrogen, as is proved by the usual products which it affords when it is decomposed by heat.

Succinic acid combines with the alkalis, earths, and metallic oxides, but few of these combinations present any important results. They have been examined by Bergman. Succinate of potassa crystallizes in triedral prisms, which are easily soluble in water; its taste is bitter: exposed to heat it decrepitates, and is decomposed. Succinate of soda crystallizes in nearly the same form; its taste is bitter, and it is also decomposed by heat. Succinate of ammonia appears under the form of needle-shaped crystals, having a saline and bitter taste, and volatile, so as to be capable of being sublimed. Succinate of barytes is of very sparing solubility in water. Succinate of lime affords long spear-shaped crystals permanent in the air, and not easily dissolved even by boiling water. Succinate of magnesia does not crystallize, but by evaporation forms a viscid mass. Succinate of argil crystallizes, according to Wenzel, in prisms.

The metallic succinates have been less examined. In general they are soluble and crystallizable. Succinate of iron, however, is insoluble, and from this property succinic acid has been employed as a test of this metal, and as a re-agent by which substances may be freed from it, succinate of potassa being added to any solution containing iron, and the succinate of iron being precipitated.

The oil and acid of amber have been employed in medicine, and have a place in the pharmacopœias, but they are nearly discarded from practice. Amber itself, when transparent, of a rich colour, and free from flaws, is cut and fashioned into various kinds of ornaments.

MELLITE or Honey-stone has been placed among the bitumens, with which, though it differs from them considerably, it has some relations. In its external appearance it has some resemblance to amber : it is of a honey-yellow colour, whence its name ; is more or less transparent, and has the property of double refraction ; its lustre is intermediate between vitreous and resinous ; its surface smooth, its fracture conchoidal ; it is brittle, and softer than amber ; has a specific gravity of 1.6. It occurs generally crystallized ; its crystals being octaedrons, dodecaedrons, or four-sided prisms acuminate by four planes. It becomes, according to Haüy, weakly electrical from friction. When heated in contact with the air, it becomes white, and, as Vauquelin remarked, burns without becoming sensibly charred, and leaves a white matter, which produces a slight effervescence with acids.

This substance is found in the layers of bituminated wood in Thuringia, and, as has also been affirmed, with mineral pitch in Switzerland. Its nature was unknown until it was analysed by Klaproth, who found it to consist of a peculiar acid, which has hence received the name of Mellitic Acid, united with argil*,—a discovery confirmed by Vauquelin, who found it likewise to contain small portions of silex and lime†.

The acid may be extracted from this substance, merely by the action of water, the water being boiled on the honey-stone ; the acid is dissolved, the argil precipitates, and by evaporation the former can be obtained in a mass,

* Analytical Essays, vol. ii. p. 89.

† Nicholson's Journal, 4to, vol. iv. p. 515.

which, when subjected to the action of alcohol, so as to separate a portion of earthy matter, may be crystallized. Vauquelin procured it in his analysis, by adding the crystals of mellite in powder to a solution of carbonate of potassa : the mellitic acid combined with the alkali, disengaging the carbonic acid with effervescence ; and on adding to the filtered liquor a little nitric acid to saturate the alkaline base, the mellitic acid was deposited in a few hours, crystallized in short prisms.

The acid thus crystallized has a yellowish tinge, and a slight acid taste, accompanied with bitterness. The colour and the bitterness may arise from a little bitumen attached to it. Exposed to heat it swells up, emits a dense smoke, is charred, and leaves a light coal ; exposed to the flame of the blowpipe, it gives at first a few scintillations like those of nitre, and is then quickly decomposed. It is sparingly soluble in water.

Mellitic acid combines with the salifiable bases, but these combinations have been only imperfectly examined by the two chemists by whom the honey-stone was analysed. Mellate of potassa crystallizes in prisms ; the crystals obtained by Vauquelin, by the process above described, appear to have been rather super-mellate of potassa, than the pure acid ; as when decomposed by heat, the coal was highly alkaline. Mellate of soda crystallizes in cubes, and also in plates. The acid neutralized by ammonia, gives transparent six-sided prisms, which become opaque from exposure to the air. Added to the watery solution of barytes, strontites, or lime, it produces immediately a precipitate of a white powder, indicating the formation of an insoluble salt. If added, however, to muriate of barytes, it gives a precipitate in needle-like crystals ; and

with a solution of sulphate of lime, a granulated and crystallized precipitate. With the solution of silver it gives a white silky precipitate; with the nitric solution of lead, a white pulverulent very heavy precipitate; with that of mercury, a white precipitate, which ammonia turns black; and with that of iron a yellow precipitate.

Vauquelin has observed, that this acid is in many of its properties similar to the oxalic, and he appears even disposed to conclude in favour of their identity. The only differences he found between them were, that the precipitate which mellitic acid causes in the solution of sulphate of lime, is less speedily manifested, and is crystalline instead of being pulverulent, like that formed by the super-oxalate of potassa; that it appears less acid to the taste than this acidulous salt; and that it swells up rather more by heat than it does;—differences very trivial, and which may arise from slight causes. One difference, however, between the two acids, more important, afterwards noticed by Vauquelin, is, that super-mellate of potassa, added to a solution of pure sulphate of argil, gave an abundant flocculent precipitate, while super-oxalate of potassa caused no precipitation.

Mellitic acid appears to be of similar composition with the vegetable acids; affording, when decomposed by heat, carbonic acid, carburetted hydrogen, an oil somewhat aromatic, a water slightly acidulous, and charcoal as a residuum. Vauquelin has observed, that it appears, like the oxalic acid, to contain a large proportion of oxygen, as in its decomposition it affords much carbonic acid, and only a small proportion of charcoal. Klaproth did not succeed in attempting to convert it into oxalic acid, by the action of nitric acid.

CHAP. V.

OF THE NATURAL POSITIONS AND RELATIONS
OF MINERAL SUBSTANCES, AND OF THEIR
FORMATION.

IN concluding the history of the compounds which belong to the mineral kingdom, it is necessary to give some account of their natural positions and relations, and of the theories which have been proposed to account for these, and for their original formation. It would be altogether foreign to the object of this work to enter on the minute details of this subject, particularly those connected with the natural positions of mineral substances: this belongs to a different science. But so far as the investigation is dependent on chemistry, or can receive any elucidation from the application of its principles, it may with propriety form a part of the chemical history of the mineral kingdom.

Its connection with chemistry, to a certain extent at least, is abundantly evident. The formation of these compound substances, though the result of operations conducted on an immense scale, must have been not less dependent on the exertion of chemical powers, in consequence of which certain elements have been combined, and certain relations established among the compounds they have formed. And although the investigation is necessarily liable to great difficulties, we are still enabled,

from our knowledge of the constituent elements of these compounds, of the laws they observe in their combinations, of the chemical properties of the compounds themselves, and of the powers of the agents which can be conceived to have operated in their formation, to arrive at some deductions, established on what approaches to scientific evidence. The period is past when the theory of the structure and arrangement of the globe could be attempted to be unfolded by a mere effort of imagination ; a nearer approach must be made to the method of induction : the positions and relations of minerals must be established by careful observation, and the speculations of geology must rest on the established laws of chemistry, and be submitted to their controul.

The surface of the globe, when we penetrate the crust of soil and of alluvial earth with which it is covered, is composed of rocky masses, of different kinds, and variously arranged. The general arrangement is that of beds or strata, parallel to each other, and preserving this parallelism to a great extent. Sometimes the same rock is divided into different strata, and frequently different rocks occur in alternating beds. These are horizontal, vertical, or more or less inclined. They are often penetrated by rents or veins in which other minerals are deposited ; and in one or other of these states, all the mineral substances are found.

A certain degree of generalization has been made with regard to these arrangements, or a number of facts relative to these positions have been established by very ample observations, whence certain classes of rocks have been formed.

Thus, it has been observed, that some rocks are almost always in strata vertical or highly inclined, and with these certain rocks often not distinctly stratified are usually connected. Others, again, are found in strata generally horizontal, or having no great inclination; and a few occur in positions, with regard to inclination to the horizon, intermediate between these. These positions are by no means arbitrary or accidental, any particular rock occurring sometimes in the one, sometimes in the other. On the contrary, they are nearly determinate, or those rocks which occur in vertical strata are seldom found horizontal, and those which are usually horizontal are seldom vertical or highly inclined; and a certain relation subsists between them, or particular rocks are usually associated.

The horizontal strata are generally lower in their position, or less elevated above the sea, or above the general level of the country; the vertical, or more highly inclined, are more elevated and precipitous, and in general form the highest mountains, and the most elevated parts of the surface of the globe.

The structure of the vertically stratified rocks is usually crystalline, while that of the horizontal is more or less earthy. The latter often contain impressions or remains of organic beings, both vegetable and animal; in the former these are never to be discovered: while, in those rocks intermediate between the two divisions, and usually inclined in their positions, we discover more or less an approach to the earthy structure, and sometimes, though more rarely, organic remains.

These classes of rocks being thus distinctly marked,

have been distinguished by different appellations. Those in vertical strata, composing the highest part of the earth's surface, and forming also, so far as has been discovered, the base on which the others repose, containing also no organic impressions, have been conceived to be of primary formation, and have been named *Primitive or Primary Rocks*; those which occur in horizontal beds, have, in consequence of this view, been named *Secondary*, or, from their position, *Floetz Rocks*; and those of intermediate formation, have received the name of *Rocks of Transition*. These are the divisions admitted in the *Wernerian System*, there being added to them, the less important classes of alluvial and of volcanic rocks. The individual rocks of these formations, it is compatible with the design of this sketch only briefly to characterize; the order of them, and their leading distinctions, are taken principally from Mr Jameson's *Treatise on Geognosy*,—the work of first authority in our language, on the details of the *Wernerian system*.

Under the class *Primitive Rocks* are placed the following: Granite, Gneiss, Mica Slate, Clay Slate, Primitive Limestone, Primitive Trap, Serpentine, Porphyry, Sienite, Topaz Rock, Quartz Rock, Flinty Slate, Gypsum, White Stone.

GRANITE is an aggregate of felspar, quartz, and mica, and, in all its varieties, these three parts are distinctly to be perceived. The felspar is generally in largest proportion, the mica in least: these, in different varieties, differ in magnitude: the colour is also various, and is generally derived from the felspar, the usual colours of which are white and red: the other general characters are derived from those of the constituent parts. This

rock is usually unstratified : it occurs also, however, in strata, which are generally of great thickness and size, is peaked and precipitous, and often forms the central and most elevated part of chains of mountains. It has been inferred to be of three formations ; the oldest, which rises to a great height above the surface, and on which other primitive rocks recline, or are wrapped around it ; a second formation in veins ; and a third resting on some of the older primitive rocks, or sometimes in veins.

GNEISS.—This, like granite, is an aggregate of felspar, quartz, and mica ; but it contains a larger proportion of mica, though the felspar still predominates, and is usually of a white or grey colour. It differs from granite in its slaty structure, being granular in the small, and slaty in the large ; and the granular structure is more apparent in some varieties than in others, so that there is a series through this rock from granite to mica slate. Gneiss is always stratified, the strata having the same direction with the structure of the stone. It is often incumbent on granite, or contiguous to it, and alternates with some other primitive rocks. It is often rich in metals.

MICA SLATE, or Micaceous Shistus, is composed of quartz and mica ; it differs from the preceding, therefore, in felspar being wanting. In its structure it is distinctly slaty : its colour is usually grey. It is always stratified, its strata being vertical, often resting on gneiss, and containing beds of other rocks. Garnet is a fossil that is often abundant in it : it also frequently contains metallic ores.

CLAY SLATE, or Argillaceous Shistus, differs from the preceding, in not being an aggregate, but apparently a simple or homogeneous rock, and, as such, has been al-

ready described, (p. 504.) Its structure is distinctly slaty; it is always stratified, the strata coinciding in direction with the slaty structure. It often forms entire mountains, and alternates with other primitive rocks; and its veins are often rich in metallic ores.

PRIMITIVE LIMESTONE. This, likewise, is a simple fossil, and as such has been described, (p. 471.), under the name of Granular Limestone. It occurs more or less distinctly stratified, and in beds of greater or less magnitude, and is considered as of different formations, the oldest being connected with gneiss, the next with mica slate, and the newest with clay slate; and these are distinguished by some differences of character, the first being of a pure white colour, translucent, and of a large grain, while, in those that are newer, the colour is not so pure, the translucence is less, and the granular concretions smaller.

Under the name of **PRIMITIVE TRAP** are classed a family of rocks, of which Hornblende is the basis. In some it is nearly pure and unmixed, as in the Hornblende rock and hornblende slate, the characters of which have been already given, (page 501). Mixed with felspar, it constitutes Greenstone, of which there are several varieties—the common greenstone, which is a granular aggregate of hornblende and felspar, and is also sometimes porphyritic in its structure, or includes crystals of felspar; and greenstone slate, distinguished by its slaty structure. Both are stratified, or in large beds, and form high conical hills. To these are to be added an aggregate of hornblende and mica, which sometimes occur in beds in gneiss and mica slate.

SERPENTINE, a simple fossil already noticed, (p. 483.), occurs as a mountain-rock, and belongs to the primitive

class. It is indistinctly stratified, occurs first in gneiss, and gradually increases in quantity in the newer formations.

PORPHYRY. This rock is composed of a basis, in which crystals of felspar, and frequently of quartz, are imbedded. The base is various, frequently hornstone or claystone, sometimes compact feldspar, pitchstone, pearlstone, or obsidian. It is seldom stratified, but rises in rude masses, often to a great height, contains no foreign beds, and rarely alternates with other rocks. Metallic veins sometimes, though not very frequently, occur in it.

SIENITE is an aggregate composed of felspar and hornblende, the felspar being the most abundant and essential ingredient, and with these are frequently mixed quartz and black mica; the hornblende is even sometimes in small quantity, and the rock is then liable to be confounded with granite. It occurs both stratified, and without any distinct stratification; frequently covers the other primitive rocks, and in particular is connected with porphyry.

TOPAZ ROCK is an aggregate composed of quartz, topaz, schorl, and a small portion of lithomarge; the three first being disposed in layers, and thus forming a slaty structure in the small, but in the great collected into large granular masses. It is of very rare occurrence.

QUARTZ ROCK. Quartz occurs not only in veins, and as an ingredient of different aggregates, but also in masses so large as to form a distinct rock. It is not distinctly stratified, and is comparatively of little extent.

FLINT SLATE, a fossil already described, (p. 518.), occurs, like quartz, in mountain masses, and also in beds in clay slate, and in veins.

GYPNUM of primitive formation has been found only in

beds of mica slate, with limestone, and in this state is of rare occurrence, having been met with only in the Alps.

WHITE STONE, the last of the primitive class, is composed principally of compact felspar, with a little mica, and has sometimes a slaty, sometimes a granular structure. It is a rock of rare occurrence.

Under the second class, or Rocks of Transition, are placed certain varieties of Limestone, and of Trap, Grauwacke, Flint Slate, and Gypsum.

LIMESTONE of transition is distinguished from Primitive Limestone, by its granular distinct concretions being much more minute; hence its fracture is more compact, being splintery or flat conchoidal. Its colours are usually variegated. It often contains organic impressions or remains; always, however, those of marine animals. It occurs either stratified, or in thick masses, in which no regular stratification is to be observed. It is supposed to be the oldest of the rocks of transition; and where it is discovered in connection with primitive rocks, usually rests on clay slate.

The TRAP rocks of transition comprehend two varieties, Greenstone and Amygdaloid. The first is an aggregate of felspar and hornblende; the mixture being sometimes so intimate, that the parts cannot be distinctly perceived, and less crystalline in its structure than the primitive greenstone. The second consists of an argillaceous base, of the nature of wacke, or approaching more or less to greenstone, containing nodules or small cavities, and the vesicles are filled with clay, chalcedony, or agate. These rocks are not very extensively distributed.

GRAUWACKE, or GREY-WACKE, is the most important

rock of this class; there are two varieties of it, what is strictly named *Grauwacke*, and *Grauwacke Slate*. The first is composed of grains or fragments of various size, connected together by a basis of clay slate, whence it receives its grey colour; these fragments are of quartz, flint slate, or clay slate. The second appears to be the same rock, in which the particles are so small as not to be apparent to the eye: with this fineness of aggregation it acquires a slaty structure. Both are stratified, and they often alternate with each other, and with beds of the other rocks of transition. They are rich in metals, and sometimes contain organic remains.

The *FLINT SLATE* of transition has the same characters as that belonging to the primitive class. It occurs in beds with the other rocks of the same family.

The third class of rocks, named *Floetz*, or, in contradistinction to the *Primitive Rocks*, *Secondary*, occur stratified, generally in horizontal beds; seldom elevated; some of them, however, covering the summits of mountains in an overlying position. The rocks belonging to it are numerous, and of different subordinate formations. The principal are *Sandstone*, *Limestone*, *Gypsum*, *Rock Salt*, *Chalk*, *Coal*, *Slate Clay*, *Basalt*, *Wacke*, *Greystone*, *Porphyry Slate*, *Basaltic*, or *Trap Tuffa*, *Greenstone*, *Amygdaloid*, *Pitchstone*, *Obsidian*, *Pumice*, *Compact Felspar*, *Claystone*, and *Clay*.

SANDSTONE consists of grains of sand or gravel, connected by a cement, which is sometimes argillaceous, and sometimes, though more rarely, siliceous; frequently, also, impregnated with oxide of iron, from which it receives a red or brown colour: otherwise it is yellowish

or white. The grains vary in magnitude, being sometimes so fine as not to be perceived, and sometimes so large as to form a pudding-stone; and the degree of induration, depending on the nature of the cement, is equally various. It is always stratified, and the strata are usually horizontal, or very little inclined. It is considered as of three formations,—the oldest, the dark-red sandstone, which often rests on rocks of transition, or even primitive rocks, its grain being coarse, its cement argillaceous, and its colour derived from iron; the second, the variegated sandstone, in which the colours are various, and usually in stripes, and which is accompanied with gypsum and limestone; and, thirdly, the white sandstone, the cement of which is generally calcareous, and which often contains traces of coal. In all of them are often organic impressions, principally derived from the vegetable kingdom. Petrified wood is found in the first.

LIMESTONE is another extensive rock of this class: it is that variety, the structure of which is less granular and crystalline than that belonging to the other formations, and which has been already described (p. 473.), under the name of Compact Limestone. It is always very distinctly stratified, the strata being horizontal or little inclined; and it abounds in marine remains. Two principal formations of it have been pointed out, the first resting on the old red sandstone, and often forming high and steep mountains; the second resting on a gypsum formation, and abounding in petrifications.

GYP SUM, of which the mineralogical description has been already given (p. 464.), occurs more or less distinctly stratified, the strata seldom rising to much height

above the surface. There are two principal formations of it, the first resting on the first floetz limestone, the second resting on the first floetz sandstone, or alternating with it, and with the second limestone formation.

ROCK SALT.—This, of which the characters have been also already given (p. 456.), rests on the first floetz gypsum, accompanied with a bed of clay, and is of very wide distribution.

CHALK is distinguished from pure limestone, as has been already remarked, by its aggregation. It is found in extensive horizontal strata, usually containing flint, and sometimes marine petrifications.

COAL.—The chemical history of this has been already given, as well as its descriptive characters. It occurs in beds of very various thickness, alternating with various rocks of secondary formation; seldom occupying an elevated position, and generally of limited extent, forming, as it were, patches, or hollows filled up with the coal, and its accompanying rocks indicating partial formations. Three principal formations of it have been pointed out, distinguished by relative position, and by the nature of the accompanying rocks. The first is the Independent Coal formation, so named, as the different deposits belonging to it are not connected, but are in insulated fields, lying over other secondary rocks, or sometimes rocks of transition: three rocks are nearly peculiar to it, a coarse-grained conglomerate stone, a friable micaceous sandstone, and slate clay; these are all stratified, and the coal occurs with them in beds: beds of greenstone and amygdaloid occur in it, and it contains much argillaceous ironstone, and small quantities of graphite, cinnabar, and some other

ores. The second is that occurring in what is named the newest Floetz Trap formation, forming frequently the lowest part of it, and being usually in a single bed, often of great thickness. The third occurs in alluvial deposits, in great quantity, being that kind of coal least remote from wood, and evidently of recent production.

SLATE CLAY, already noticed (p. 505.), the Shale of some mineralogists, very frequently accompanies coal, in thin beds. It often contains a great variety of petrifications, especially of vegetables.

There remains a series of rocks, belonging to what is named the New Floetz Trap Formation, which are found in a very peculiar relation, not in connected chains, or conformable with the other strata on which they lie, but isolated, covering them in an unconformable position, and almost always much broken and interrupted. Besides some rocks which occur in the other formations, as greenstone, amygdaloid, pitchstone, compact felspar, and clay stone, there are peculiar to it basalt, wacke, greystone, porphyry slate, and basaltic or trap tuffa.

BASALT, the characters of which, as a simple fossil, have been already given (p. 503.), is usually unstratified, rising often to a considerable height, and forming hills, well distinguished by their conical or table-shaped summits: it occurs also in beds and in veins.

WACKE has been already described (p. 503.), as a fossil intermediate between basalt and clay, and often passing into the one or the other. It occurs in beds or veins.

GREYSTONE is an intimate mixture of white felspar and blackish hornblende, the felspar predominating, and

the grains being smaller than in greenstone. It is often connected with basalt, and passes into it.

PORPHYRY SLATE, or Clinkstone Porphyry, is an aggregate, the basis being clinkstone, in which are imbedded crystals of glassy felspar. Its colour is usually grey, of different shades, blackish-green, and sometimes brown. Its fracture is splintery, and, in the large slaty, it is semi-hard, or hard; is more or less translucent on the edges. Like basalt, it forms single conical hills, though not so regular: it occurs sometimes columnar, and also in veins.

BASALTIC, or TRAP TUFFA, appears to be formed from the disintegration of basalt, amygdaloid, sandstone, and other rocks of a similar nature, as it is composed of fragments of them, frequently with remains of vegetables, as pieces of wood, agglutinated by an argillaceous cement. The fragments vary much in size. It occurs in beds, which are usually horizontal, and sometimes alternate with basalt.

Besides the rocks peculiar to what has been named the Floetz Trap Formation, there are some found in it which also occur in the others. Greenstone is very frequently found in beds, and, as it occurs in this formation, is not so crystalline, nor its concretions so large as in the others. Amygdaloid, having wacke for its basis, in which are imbedded calcareous spar, chalcedony, agate, quartz, &c. likewise occurs. Pitchstone was discovered by Mr Jameson in this formation in Arran, and has since been found in other places. Obsidian has been found alternating with basalt and porphyry slate. Pumice was usually regarded as a volcanic product, but is said to occur distinctly stratified, and alternating with basalt and porphyry.

Compact felspar and claystone both occur in beds in the trap formation, as do likewise sandstone, ironstone, coal, gravel, sand, and clay.

To the rocks now described are to be added the classes of alluvial and volcanic formation. The former arise from the decay of rocks, and other processes at present going on at the surface of the earth; their materials deposited in plains and hollows, consist of beds of clay, sand, bog-iron ore, and decayed vegetable matter. The latter have been very imperfectly described.

In attempting to discover in what manner these arrangements have been established, and the immense number of different substances found in the mineral kingdom formed, we no doubt engage in an investigation involved in much difficulty, and which probably does not, in the present state of our knowledge, admit of a perfect solution. Yet some advantage may be derived even from speculations on this question, not only in giving interest to it, but in suggesting inquiries, and in enabling us to generalize and arrange our observations: nor is it so far beyond the reach of investigation, as to preclude the hope of some certain conclusions being drawn.

The leading fact on this subject, and the basis of all our reasonings, is, that the surface of the globe has at one time been in a fluid state, to the greatest depth, as well as the utmost height, which have been reached. The imagination finds a difficulty in admitting such an induction, and it is this which gives some appearance of extravagance to the speculations of geology; yet it is established on evidence, which it is impossible to resist or controvert.

The mere arrangement of the great masses at the surface, is a sufficient proof of their previous fluidity, or at least of the deposition of their materials from a fluid state. The parallelism of their beds, it is obvious, can be accounted for on no other supposition; it could have been produced only by deposition from a fluid at rest, and, as it extends over the entire surface of the earth, it establishes the original fluidity of the whole. The materials of which many of these strata are composed, establish the same truth. They are often fragments cemented together, which proves, at least, the interposition of a fluid by which their continuity has been effected. The foreign substances they so often contain, organic remains for example, necessarily lead to the same conclusion, since, to admit of the introduction of these substances, the matter of these rocks must have been in at least a soft state. The crystalline structure, and the regular crystallization of many of their ingredients, affords another proof of their previous fluidity, which must command unlimited assent; for every species and degree of crystallization implies a state of fluidity, in which the particles of the body were allowed to arrange themselves in certain positions in which they were disposed to unite, and in which no resistance was opposed to any regular figure being assumed. Lastly, the spheroidal figure of the earth itself is a demonstration, that its surface, to a depth much greater than we have penetrated, must have been at one time fluid, or at least soft and yielding.

Fluidity can be conceived to be produced only in two modes, either by fusion or by solution; and from each of these has it been conceived that the solid matter of the globe, or of its surface, had been fluid, thus forming

two systems, which have long been considered as opposed to each other. According to the one, all mineral substances have been originally melted or softened by heat, from which state they have consolidated; according to the other, they have once been dissolved in a fluid, and have concreted from it under different circumstances, so as to give rise to the appearances they now exhibit.

Of the modifications of the igneous system which have been maintained, that view of it given by the late Dr Hutton is undoubtedly superior to any other. It is at present supported by some distinguished names; and it is it which may be considered as opposed to the theory which ascribes to minerals an aqueous origin.

The leading feature of Dr Hutton's system is, that it is not designed to account merely for the present arrangement; nor does it proceed on the supposition, that this is the same that has always existed. On the contrary, a system is traced, in which successive arrangements, and an adaptation of means by which these are produced, is developed: a series of operations is unfolded, by which the elevated land is worn down, its materials carried to the bottom of the ocean, again consolidated, and again raised, so as to give rise to a succession of habitable worlds.

Dr Hutton remarks, that, from the structure of the elevated part of the globe, and the nature of the operations to which it is subjected, it is necessarily liable to decay, and that there is a process constantly going forward, the tendency of which is to reduce it to one uniform or level surface. Its most solid strata moulder gradually from exposure to the air, and are worn down by the attrition of water; and from the declivity of the land, and the flow

of water, the disintegrated materials must necessarily be carried to the bed of the ocean.

From many appearances which are presented by the present strata, Dr Hutton supposed there is reason to conclude, that they imply the prior existence of strata similar to those which now exist, and that, from the disintegration of the former, the latter had originated. He supposed, too, that there is sufficient reason to infer, that their consolidation, and subsequent elevation, had been effected by the agency of fire.

These conclusions are connected into one system, to which, no doubt, belongs the praise of originality of conception and grandeur of design. Taking the elevated land as it exists now, or at any other period, it is always suffering decay; and its disintegrated materials must be carried forward, and spread over the bottom of the ocean in parallel beds. There, it is inferred, they are subjected to the operation of subterranean fire, by which they are more or less perfectly fused, and thus brought into a consolidated state; and, by the expansive force of the same agent variously exerted, they are elevated above the ocean, and the appearances are presented which our strata exhibit. Our world has thus been formed from the decay of one that preceded it, and it is now furnishing the materials from which another will be raised. This great natural operation, it is remarked, is without limit as to time; or there can be discovered in the system itself no vestige of a beginning, and no prospect of an end.

The subterranean fire operating under the pressure of the ocean, must produce effects different from those which would result were such pressure not applied: it

must prevent the decomposition of substances containing a volatile ingredient ; and this, in its turn, may influence the fusion and consolidation. The application of heat under such compression, forms, accordingly, a peculiar feature of the Huttonian system ; and the admission of it solves difficulties which would embarrass any other hypothesis of the igneous origin of minerals.

The more or less perfect fusion to which the disintegrated materials had been subjected, and the mode of elevation, account, it is supposed, for the principal appearances of our present strata. Some have been only imperfectly fused or softened, and hence the crystalline structure has not been acquired, nor even the fragments from which they have been formed, or the foreign substances introduced into them obliterated. When heaved up with little derangement, they present that horizontal stratification they must have received from their deposition ; or if the expansive force has been differently exerted, they may be placed in inclined or vertical strata. These consolidated strata are likewise supposed to be invaded by irruptions of matter, more completely fused or liquid, which disturbs and interrupts their continuity, and alters their relative position ; and which pressed into every empty space, consolidates and forms stony masses, in which no regular stratification is observed. Such is conceived to be the origin of granite, porphyry, and basalt. Veins are supposed to be filled in a similar manner, by injection of liquid matter.

For the details of this system, I refer to the view of it by Professor Playfair, in his "Illustrations of the Huttonian Theory of the Earth."

The modification of the opposite doctrine, of which

Werner is the author, is that which is at present received by those geologists who consider water as the agent by which the surface of the earth has been arranged. It is fully stated in Mr Jameson's Treatise on Geognosy. A short view of it is also given in the 55th volume of the *Journal de Physique*.

From the appearances of the strata, and of the minerals they contain, it is concluded, that they must at one time have been fluid; and from these appearances, as well as from a number of facts respecting their nature, it is inferred, that this fluidity must have arisen, not from fusion, but from solution by a common fluid. Water being the only liquid found in sufficient abundance for this purpose in the globe, is supposed to have been that in which the materials of the solid strata have been dissolved or suspended, and from which, by deposition or crystallization, have been formed the various masses which the surface of the earth presents. The view of the formation and arrangement of these, is intimately connected with the distinctions already explained, of rocks into primary, transition, and secondary, as these, in the Wernerian system, are conceived to have been formed at different periods.

The rocks which are denominated Primitive, are those which form the most elevated parts of the surface of the globe, and on which, so far as has been traced, all the others are imposed or recline. They are generally highly crystalline in their structure, and they contain no organic impressions or remains. From these three leading facts with regard to them, certain inductions as to their formation are made.

From the first fact, that the other rocks rest upon them,

it is inferred, that they must have been of earliest formation, that they are the first products of that consolidation from which the structure of the surface of the globe has been derived. From the second fact it is inferred, that they must have been chemical deposits, or the transition of matter in solution to a solid state. And from the third, that their production must have been anterior to the creation of animated beings.

It is conceived, then, that at a period prior to that at which the present arrangement had been established, there had covered the surface of this planet, to a height at least equal to that of our most elevated mountains, a compound fluid, of which water had probably been the basis, as it still is of the ocean, and in which had existed, in a state of solution, the saline, earthy, and metallic matter now found in the mineral kingdom. From this fluid consolidation had taken place, probably from the exertion of mutual affinities between the substances dissolved; and by this consolidation had been formed a number of successive deposits or layers around the globe, the remains of which now constitute the Primary Rocks. And as the outgoings of these strata, as they succeed each other, are observed to become lower, it is inferred, that the common fluid from which these formations had taken place, had gradually diminished in height.

The strata of transition have a little lower level, compared with the primitive, or they do not rise to the same height; and when they are discovered resting on the primitive, their outgoings are still lower. From this it is inferred, that the common fluid from which these formations had taken place, had still continued to diminish in

height, and, from the circumstance of subsidence, another character belonging to the formation originated. The primitive rocks, now partly exposed above the surface of the water, or nearly so, would be liable to the changes arising from its agitation; fragments would be broken off, and disintegration take place, and thus a mechanical deposition would be mingled with the crystalline consolidation. These, accordingly, are the characters of the rocks of transition: they repose on the primitive rocks, are less elevated, and their structure, at the same time, is more earthy, or less crystallized. In other respects, they were the same, or formed general deposits, which encircled the globe. From the fact, that some of these rocks contain remains or impressions of marine animals, it is inferred, that some of this class of beings had now been formed: no traces of land-animals or of vegetables have been discovered in them; and the impressions which do exist, are those of animals unknown, but apparently of the lowest order in the scale of life.

The level of the waters still continuing to diminish, the disintegration of the rocks already formed would become more and more considerable; mechanical deposition would become, therefore, more copious and abundant, while, at the same time, from the concretion of the greater part of the solid matter which had been in solution, chemical deposition would become more scanty. This, accordingly, gives the characters of the class of rocks formed from this period, those denominated secondary. These are arranged in horizontal beds or strata, and their structure is generally earthy, shewing the prevalence of mechanical deposition, and that only so much chemical con-

solidation had taken place, as cemented the fragments and minute particles of which they are composed. Organic remains and impressions are abundant in them,—a proof of their formation posterior to the production of animated beings, and a proof too of the length of period during which their formation had been accomplished.

Werner supposes the great formations to have been universal, or to have extended round the globe, and to have successively varied so as to give rise to the different rocks, the formation of these too being frequently successively resumed. According to this view, granite formed the first formation with which we are acquainted; then gneiss; then mica slate, and so on, these having often included in them beds of other rocks, or partial formations. We can no where perceive an universal formation of this kind, or a continued plane round the globe composed of one formation. But this is supposed to arise from the disintegration to which all the rocks have been subjected from natural operations. And although we can no where trace the entire formation, yet it has been found more or less interrupted over the whole surface; or in many countries widely remote, the same rock, with the same accompanying fossils and relations, is found,—a strong proof of the probability of the original supposition.

It is partly from the disintegration, partly perhaps from the inequalities of the nucleus that the strata were deposited on, and partly from the unequal thickness of the strata themselves, that the present inequalities of the earth's surface have arisen. And as the primitive rocks are those which, from their crystalline structure, have had the greatest hardness, they have been most capable of resist-

ing the disintegrating operations, and hence form the most elevated summits, while the others repose on their sides.

Besides these formations, which are conceived to have been universal, there are, as has been already remarked, two subordinate formations, which have peculiar characters. One of these is what is named the Independent Coal Formation, so named because coal is the chief mineral in it. This is conceived to have been only partial, or, although very widely diffused, not to have formed a continuous bed, but to have been deposited in patches, as it were, or in hollow beds. It is superimposed on the transition rocks. The other is the Floetz Trap Formation, composed chiefly of basalt, wacke, and greenstone. This is conceived to have been the newest formation, to have been therefore placed over the others. The rocks belonging to it have a very peculiar character. They are insulated, and not conformable in direction with the other strata, but merely resting upon them, generally in detached spots. From this singularity Werner has inferred, that the water which had subsided had again risen rapidly, had deposited during this rise the matter of these rocks, and had again returned to its former level. They have suffered too more complete disintegration, and hence we perceive them now principally insulated, rising among the secondary strata, and sometimes forming the summits of the rocks of transition. A gradation has been traced in the formation from basalt to sand and clay; and the clay or sand often forms the undermost bed. It frequently contains organic remains, and these often of vegetables, even entire trunks of trees, shewing its more recent formation.

In the consolidation of the strata, it is supposed that rents happened ; and these being filled by the common fluid, chemical deposits were formed within them, filling them up. And as the fluid in such rents would be protected from agitation, the crystallizations are often extremely regular. These form mineral veins.

Lastly, there are certain operations still going on at the surface of the earth, by which changes and new formations are effected. These are the operation of volcanoes, and the overflowing and filtration of water, producing alluvial beds. These, however, are evidently trivial, and scarcely require to be considered in a theory of the earth.

It would be impracticable, within the limits I must observe in this sketch, to enter on any minute examination of the comparative merits of these theories, and to do so would even be in some measure foreign to the objects of this work. As it is a question, however, of some interest, I shall add a few observations on such parts of the discussion as receive illustration from chemical principles, or do not involve much mineralogical detail. The evidence for the particular doctrines of the Wernerian theory, I may remark, must rest on a very ample induction from extensive observation, as it is only by such observation that the view of the relations of mineral substances, which that theory exhibits, can be established as more than hypothesis. And as Werner himself has not published the observations, and of course the evidence on which these views are founded, they rest at present (or at least this is true with regard to the greater number of them) very much on the authority of his name, and admit, therefore, of scarcely any observations.

But there is another view more general, under which the theory may be considered, relating chiefly to its first principle,—that minerals have had an aqueous origin, and that the arrangements we observe in the structure of the globe, have been effected by the agency of water. This rests less on any individual observations; it is what may be decided on from evidence already known to geologists, and which has been often the subject of discussion; and it is under this point of view that I would contrast the Neptunian with the Huttonian theory*.

In comparing the probability of the first principles of these systems, a formidable difficulty is at once presented, in the *postulata* which the Huttonian hypothesis requires. It supposes the consolidation of minerals, and the elevation of our strata, to have been effected by the action of subterranean heat, and that from this cause, not merely has the present arrangement originated, but a succession of worlds, extending to an indefinite period. The question that naturally occurs, is, What is the source of the heat by which operations so immense are to be performed?

The extent of its agency must be apparent, from the necessity of supposing that it must have operated at every part of the circumference of the globe, in order to consolidate the materials which are every where deposited at the bottom of the ocean, or give rise to the strata

* The observations in the text I take principally from a small treatise, (*Comparative View of the Huttonian and Neptunian Systems of Geology*), which I some years ago published on this subject, in which I endeavoured to defend the Neptunian system.

which every where exist. And the intensity of this heat may be appreciated from what we know of the infusibility of many rocks. They consist of substances which cannot be melted even by the most intense heat. Quartz exists in many rocks: it is found distributed in veins, often regularly crystallized, and it forms, of itself, mountain masses, yet it is perfectly infusible, not only in the heat which any furnace can excite, but, even in minute fragments, is not melted by the much more intense heat from combustion, excited by a stream of oxygen. Many other fossils are nearly or equally infusible, which, from their crystalline structure or form, must have been at their formation in a liquid state, and which, of course, if this was effected by that power, must have required an intensity of it beyond what the imagination can well conceive.

The Huttonian Geologists have been willing to lessen this difficulty as much as possible, and have observed, that substances of a compound nature, and containing volatile ingredients, may be more fusible when the separation of these is prevented by compression, than they appear to be when they are exposed to heat without compression being applied. Marble or limestone was found by Lavoisier and Saussure to be incapable of being fused in the focus of a burning mirror, or in the more intense heat in the flame of the blowpipe, excited by a stream of oxygen gas. But, under such circumstances, it was remarked, that marble must have been decomposed, and its carbonic acid have escaped: the experiment, therefore, only proves the infusibility of lime. But it is possible, that when lime is combined with carbonic acid, its fusion may be facilitated, or the entire compound may be more fusible

than the lime itself. The truth of this conjecture has been established by the excellent experiments of Sir James Hall *, which have shewn, that under a compression much less than that which would be afforded by the medium depth of the ocean, carbonate of lime may be fused by a heat comparatively moderate.

The difficulty with regard to the fusibility of minerals, so far as it relates to carbonate of lime, is therefore removed. But this is of little avail in obviating the general objection; for substances remain, quartz for example, equally requiring the intense heat which was formerly supposed necessary to melt them, which contain no volatile ingredient, and the fusion of which, therefore, compression cannot promote; and with regard to these, as well as the necessity of assuming an immense heat, to produce that expansive force by which continents are to be elevated, the difficulty remains in its original force.

From what source, then, it is to be repeated, could such a heat have been derived? None can be imagined but combustion. But no accumulation of combustible matter that can be supposed, would be sufficient for this purpose,—for supporting a heat of such intensity, so widely diffused in its operation, and so long continued. The access of oxygen is equally indispensable, and in the subterranean regions where this heat operates, no supply of this principle can even be conceived, by which such a heat could be excited and preserved.

And, let it be granted that a heat was once excited, capable of fusing and consolidating the present solid

* Edinburgh Philosophical Transactions, vol. vi.

matter which forms the surface of the globe; this is only a part of the process, which, in the Huttonian hypothesis, is supposed to be constantly carried on. The theory is designed not merely to explain the formation of the present elevated land; what Dr Hutton, and those who have adopted his views, have regarded as its high excellence, is, that it points out a series of operations which are indefinitely renewed. In the present strata, we discover, we are told, the wrecks of a former world similar to our own, and which had been formed in the same manner. Nay, there are appearances presented in some of them, which Dr Hutton regards as indicating the existence of at least one other world prior to that which had existed before ours. Here, therefore, must have been heat excited and preserved during the formation of three worlds, each of these, according to Dr Hutton's calculation, requiring millions of years for its destruction and renovation. The imagination is at a loss to conceive the quantity of heat which such operations require; and the necessity of admitting such suppositions is perhaps a sufficient refutation of the hypothesis.

But there is another point of view under which this may be placed, leading to a conclusion still more directly hostile to the Huttonian system. The essential and characteristic property of the power producing heat, is its tendency to exist every where in a state of equilibrium, and hence it cannot be preserved without loss, or without diffusion, in an accumulated state. In the theory of Hutton, the existence of an intense local heat, acting for a long period of time, is assumed. But it is impossible to preserve caloric in an insulated state. Waving every ob-

jection as to its production, and supposing it to be generated to any extent, it cannot be confined, but must be propagated to the contiguous matter. If a heat, therefore, existed in the central region of the earth, it must be diffused over the whole mass; nor can any arrangement effectually counteract this diffusion. It may take place slowly, but still it must always continue progressive, and must be utterly subversive of that system of indefinitely renewed operations, which is represented as the grand excellence of the Huttonian theory.

It has been said, that in urging this argument, an unfair advantage has been taken of some observations of Mr Playfair, designed to obviate the difficulties which attend the production and maintenance of heat, according to the Huttonian system. I cannot perceive the least ground for this observation. Had the argument been confined to the reasoning of Mr Playfair, it would still have been perfectly in point; for it was incumbent on the defender of the theory to give some account of the origin of the heat assumed to explain appearances in the structure of the globe, or acknowledge this difficulty which might be urged against it; and, of course, if such an explanation were given, it was in point to shew its insufficiency, if this could be done. But although this would have been perfectly consistent with fair reasoning, the fact is, that the above argument against the theory, is altogether independent of Mr Playfair's observations on the mode in which the generation of the heat might be accounted for. The argument is twofold: 1st, It is designed to shew, that no source of heat can be imagined, that can account for the production of that power in the central regions of the globe, to the extent required in the Huttonian hypothec-

sis; and, 2dly, That, even granting such a source of heat, its existence and continuance, as supposed in that hypothesis, are impossible, as involving suppositions inconsistent with the known laws of this power. This latter has no relation to the former; it proceeds on propositions unconnected with it, and neither they nor the inference drawn from them have, I believe, been invalidated. It still appears to me a demonstration of the fallacy of the first principle of the Huttonian system, for it is founded on a physical fact, incontrovertible, and is deduced from that fact by a single inference equally undeniable. It will not be disputed, that the tendency of caloric is to diffuse itself over matter, until a common temperature is established. Nor will it probably be denied, that a power, constantly diffusing itself from the central part of any mass of matter, cannot remain, for an indefinite time, locally accumulated in that mass, but must at length become equal or nearly so over the whole. To avoid the argument, the theory may be corrected: it may be supposed that there has been only one world before the present one, and that the system will not continue longer than ours. Even this, I believe, would still be sufficient to admit of the demonstration being applied to it; but, at any rate, this is no longer the Huttonian system,—that system, “where no latent seed of evil threatens final destruction to the whole, and where the movements are so perfect, that they can never terminate of themselves*,” if thus corrected, it must descend from the elevated rank eloquently claimed for it, and is divested of those

* Illustrations of the Huttonian Theory, p. 127.

attributes, which “ distinguish it from all other theories of the earth, and point it out as a work of great and original invention *.

The conclusion urged in the preceding reasoning, has also been attempted to be obviated, by the supposition that this subterranean heat may not always operate ; that it may lie dormant for ages, then be excited, and, when it has produced a certain extent of consolidation or elevation, again become quiescent. On such a hypothesis, we are entitled to inquire, By what agency is this convenient extinction and renewal of the heat regulated ? Why does it cease, after having operated for a certain period ? If from exhaustion, by what process is it renewed ? And in what manner is it effectually confined, during the time in which it continues in an active state ? How, too, should it have been able to have penetrated around the circumference of the globe, to the bottom of the ocean, that is, to within a few miles of the surface, and to such an extent as to have consolidated the loose materials there deposited, and fused even those which are most refractory ? Yet beyond this it should not have reached. In a system professing to be so eminently marked by traces of design, and of an exact adaptation of means, it is not allowable to advance such loose hypotheses ; and, in order to avoid difficulties, to assume multiplied operations and arrangements, for the production of which no cause can be assigned, improbable in themselves, and bearing all the features of fictitious accommodations to what the system requires.

The chief difficulty which occurs with regard to the

* Illustrations of the Huttonian Theory, p. 485.

first principles of the opposite theory,—that which supposes minerals to have been formed by the operation of water,—is the insolubility of the greater number of them, either in their compound or elementary state in water. To affirm, it is said, “that water was ever capable of dissolving these substances, is to ascribe to it powers which it confessedly has not at present, and therefore is to introduce an hypothesis not merely gratuitous, but one which, physically speaking, is absurd and impossible.”

It would be a sufficient answer to this objection, to appeal at once to the fact, and observe, that substances which we find insoluble in water, exist in solution in that fluid in nature, or have been undeniably deposited from it. Thus, *silex* is found in solution in a number of mineral springs; and siliceous stalactites, the aqueous origin of which is not in the least ambiguous, occur, some of which are even crystallized on the surface, in the usual forms which quartz assumes.

But, independent of this brief and decisive mode of obviating the objection, various answers may be given to it. The most satisfactory is probably to be derived from the principles established with regard to the affinities of bodies, and the circumstances by which these are influenced.

It follows from these principles, that all bodies have mutual affinities, and that these are prevented from being efficacious in particular cases, only by the predominance of certain circumstances by which affinity is counteracted,—cohesion, elasticity, and various other qualities of bodies. If we take a piece of quartz, we no doubt find it insoluble in water; but this is not owing to the absence of any attraction between them, but to the cohe-

sion of the quartz, by which that attraction is counteracted. The proof of this is, that when that cohesion is overcome, the silex, of which quartz is composed, can actually be dissolved, as we find, in decomposing silicated potash by an acid, the silex not being precipitated if a large quantity of water be present. To conclude, therefore, because minerals are now insoluble in water, that their elements, free from all aggregation, could not have existed in solution in that fluid, is obviously a mistake, as it overlooks entirely the very circumstance to which their insolubility is to be ascribed.

But farther, in judging of the possibility of these substances having consolidated from aqueous solution, it is a very erroneous supposition, that each of them could owe its previous solution only to the affinity which the water exerted towards it. Were all the elements of the mineral kingdom presented to each other in a state of extreme division in water, each would exert affinities to the others which were present, and the whole might be rendered soluble, not merely from their affinity to the fluid, but from the mutual affinities which were thus exerted. This is the mistake of those who argue against the Neptunian theory. We find, that minerals, as they now exist, are generally insoluble in water; we discover that their constituent parts are even sparingly soluble. It is hence inferred, that they could never have been in a state of solution. The effect of the affinities of each substance to every other is neglected; and it is erroneously imagined, that the solution of the whole must be ascribed merely to the affinity of each to the common fluid.

This reasoning is not hypothetical: it is established by

very ample induction, and examples can be given, in which the cause now stated actually produces the very effects which are ascribed to its operation. Thus, Scheele found, that if argil be precipitated from its solutions by lime, an excess of lime re-dissolves it. If silex and argil be combined together, by mixing the alkaline solution of each of them, the precipitate, consisting of the two earths, is soluble, as Guyton and Darracq found, in distilled vinegar,—a fluid in which silex by itself is perfectly insoluble. And Mr Chenevix observed, that a solution of potash, boiled on argil and lime, dissolves more lime than the water alofe of the solution would do, while this portion only is dissolved if the alkaline solution alone be boiled on the lime. In all these cases, therefore, the affinity of a substance not very soluble, promotes the solution of another, and they illustrate well the effects that may result from these reciprocal attractions.

It is unnecessary to expand this argument. In the common fluid from which minerals are supposed to have been consolidated, were present the earths and metals, the inflammables, and the quantities of oxygen and hydrogen, which now exist in the mineral kingdom, and probably also the elements which form the ocean and the atmosphere. The effect which would result from the exertion of such numerous affinities, cannot be limited; and if we find reason, from the appearances of the mineral kingdom, to infer, that the substances composing it have consolidated from solution, it will be no objection to that conclusion, that these substances are no longer soluble in the fluid in which they had been formed, or rather, to speak correctly, in the fluid which remained after their formation.

In the adaptation of these theories to the phenomena of geology,—the remaining point of view under which they may be considered, there is a leading distinction between them, which gives to each a very different character; and this, as it shall be found to accord or not with the established order of nature, may enable us, on this ground likewise, to decide on their truth.

The natural tendency of the Huttonian hypothesis undoubtedly is, to consider the substances of the mineral kingdom under a very general point of view; or, in conformity to its principles, it admits of few distinctions, in the nature, structure, or position of the great masses of the globe. These have originated from the mingled materials of a former world brought by the rivers to the ocean, deposited in its bed, and consolidated and elevated by the operation of a subterranean heat. The strata thus formed may differ somewhat in their degree of induration according to the intensity of the heat to which each has been exposed, or they may differ in their elevation and position, being vertical, horizontal, or more or less inclined, according to the exertion of the expansive force by which they have been raised. But we perceive no cause why other differences should exist among them; why some should differ entirely, for example, in their chemical nature and composition from others; nor do we perceive any principle whence a certain relation should be established among them; why a certain family of rocks should be always in connection, and be distinguished by common characters. In the Wernerian system, on the contrary, such differences and such connections are to be looked for, and are conformable to its principles. The greater

number of rocks are regarded as chemical deposits; as consisting of elements brought into combination by the exertion of certain affinities; and these being necessarily varied, at different periods, in consequence of the very formations themselves, deposits of different kinds may be expected to be formed; while each great formation shall, at the same time, from the uniformity of the process from which it originated, have certain common characters. An order of this kind, therefore,—a diversity in the chemical nature of the deposits, while a certain relation likewise exists between them, is conformable to this system; or rather, the system is adapted to such an order, supposed to be sufficiently established by observation.

To decide between these hypotheses, therefore, on the grounds of their adaptation to the phenomena of geology, we have only to inquire, if such an order exist in nature; and, from the observations already made, this is an inquiry on which perhaps there can remain little doubt.

Independent of the minute distinctions of the Wernerian system, as to the different formations, the order they observe, and their relations to different minerals, which are confessedly irreconcilable with the Huttonian hypothesis, and which are therefore contested; it can scarcely be questioned, but that there are real grounds for the great distinction into primitive rocks, rocks of transition, and secondary rocks; or, without implying any hypothesis, which the terms used to characterise these might suggest, that there are families of rocks, possessed of the general characters by which these have been distinguished.

Who can doubt that granite, gneiss, mica slate, clay slate, and that variety of limestone, highly crystalline in

its structure, and destitute of organic remains, have certain common characters, are generally in connection, and often alternate ; while there are not to be found among them those rocks which are usually denominated secondary ? and, on the other hand, that among the secondary rocks,—the common sandstone, the compact limestone, &c. gneiss, mica slate, and the other rocks distinguished as primitive, are not to be found ? Yet on what principle, in conformity to the Huttonian hypothesis, can this arrangement be explained ? The whole have been formed from similar materials at the bed of the ocean, and we neither perceive why these differences should have been established among them, nor whence should have arisen those common characters by which each class is distinguished, and that relation by which some are associated, and others separated.

Thus, to consider the question as relating to one point, why should those rocks distinguished by their highly crystalline structure, be usually (when their stratification can be observed) in strata vertical or highly inclined ; and, on the other hand, why should those of an opposite character be usually horizontal ? Both, according to the theory, have been originally deposits of loose materials, in horizontal beds. The crystalline structure is supposed to be the effect of more perfect fusion ; the vertical position, the result of the peculiar exertion of the expansive power by which they have been elevated ; but, as the elevation is subsequent to the consolidation, there appears no cause why those only should be brought into this vertical position which had previously been perfectly fused ; or there is no connection between these effects, in consequence of

which the one should accompany the other. Neither is there any cause why the strata which had been only imperfectly fused, and had therefore retained more of the earthy structure, should likewise have been elevated so as to have assumed only a horizontal position. On the contrary, for any thing that the theory points out, we should find all of them in every variety of position, and every diversity of connection; and from the operation of the agent it employs, we should expect, indeed, only disorder and confusion.

Or, to take another leading feature in the characters of these rocks, why should the one class contain no organic remains, while these are abundant in the others? Both are supposed to be formed from loose materials deposited at the bottom of the ocean, where these substances must have been equally intermingled with them. The only solution that can even be conceived of this difficulty, is, that in the one class of rocks, those denominated primary, the fusion had been more perfect than in the others, and these remains had been obliterated. But this solution will not apply; for we find, from the structure of some of the secondary rocks, that they must be supposed to have been in as perfect fusion as the others, and yet the marine remains or impressions are still abundant in them. Thus, the secondary limestone is often penetrated with veins of calcareous spar, which, from its structure, must, by the Huttonian Geologist, be supposed to have been in perfect fusion; and even the very substance of the shells found in it often exhibits the crystalline fracture. Nay, we learn from Sir James Hall's experiments, that carbonate of lime may be fused, and yet the form of a shell ex-

isting in it be preserved. In other fossils, too, we find organic impressions, though these have been supposed to have been completely liquid. Thus, flint is supposed, in the Huttonian system, to have been injected in the liquid state from fusion, into the strata of chalk in which it is found; yet it often forms delicate marine petrifications. According to the Huttonian theory, therefore, fusion does not obliterate organic remains, and it thus fails in accounting for one of the leading and most instructive facts in the natural history of the globe,—that in the strata denominated primitive, no organic remains are found.

It is scarcely necessary to remark, that the Wernerian theory accords perfectly with these facts. The primary strata are supposed to have been chemical deposits, whence their crystalline structure and vertical stratification have originated, and to have been prior in their formation to the creation of animated beings, whence they contain no organic remains.

It may be farther inquired, how, on the principles of the Huttonian theory, the chemical distinctions between these rocks have been established, and, in particular, how substances of a determinate composition, with little intermixture, have been formed? In the disintegration of the ancient world, the materials must have been brought to the ocean in a mingled state, and by what process could these have been separated, so as to give rise to such formations? Let it be considered in what manner this disintegration has been effected. A large tract of elevated country is exposed to the action of air and water, from which it moulders down; the disintegrated fragments are carried off by the water which flows over its surface,

and by the rivers are deposited in the ocean, in a state of perfect intermixture. Now, although it should be granted, that from difference of specific gravity, or of diffusibility in water, some degree of separation might be effected, it is not possible that this should have taken place to the extent necessary to form certain substances of uniform and determinate composition; and the chances are infinite to one, that if this did happen, it would not be regularly repeated at successive periods, so as to reproduce these in alternating strata, and give rise to that order and connection of them which we observe in nature. Above all, it is plain, that it must be merely mechanical; that it can only bring together particles of similar specific gravity, not particles of the same chemical composition; and that it could never effect such a perfect separation as to leave one kind of matter pure and distinct. To take an example which will place this in the clearest light; how, it may be inquired, have the strata of gypsum, which now exist, been formed? Suppose this substance to have constituted part of the ancient world; it no doubt would be subject to disintegration in common with the other strata, and its disintegrated particles would be carried to the ocean. But they must necessarily be brought there, and deposited in a state of intermixture with the materials of these strata, and must, in this state, have been consolidated by the subterranean heat; nor is it possible to imagine a cause, by which the particles of gypsum should have been separated from the others, been brought together, and thus have given origin to the beds of that fossil in a pure state which now exist.

I can scarcely prosecute this discussion from the phe-

nomena of geology farther, else it might be remarked, that the Huttonian hypothesis fails to account for the circumstance of stratification itself; since, admitting that the materials of the strata were deposited from the ocean in beds, the original lines of division must have been obliterated by the subsequent fusion or softening, aided by the incumbent pressure; that with regard to the alternations of strata, many difficulties present themselves, the more fusible being often placed beneath the less fusible, without being more perfectly consolidated; and even beds or layers of unconsolidated matter, as of sand or clay, being interposed between strata in a high state of induration; and that the deposition of some stratified substances could never have taken place. Gypsum, for example, is soluble in 500 times its weight of water, and, in its disintegration from the strata of a former world, must have been retained in solution by the water of the rivers or the ocean, and could never have been deposited or accumulated in beds. Rock salt is an example of this still more obvious, which is even admitted by the defenders of the Huttonian theory, and an hypothesis of a most extraordinary nature introduced to account for its formation,—that the central fire had occasionally burst forth at the bottom of the sea with such violence, as to have driven off the incumbent water in vapour, and “by such action often repeated on the same spot, may have produced those great accumulations of saline matter, that are actually found in the bowels of the earth,”—an hypothesis, the extravagance of which no amplification can place in a clearer light; which will be found deficient as applied to the phenomena, and which breaks the uniformity of the

theory, and introduces a cause accidental in its occurrence, and in the highest degree irregular and violent in its operation, to account for appearances which are not insulated or irregular, but are in relation with, and form part of the general system.

I might proceed, too, to examine how far the chemical properties of individual minerals agree with the supposition, that they have been formed by water or by fire. As this discussion is already, however, extended too far, I shall only select one general fact of this kind, than which none can be imagined more decisive of this question.

The fact to which I allude, is the regular crystallization of one substance within the mass of another; specimens of which are abundant in the mineral kingdom. It is obvious, that both substances must have been in a liquid state: the crystallized substance must have been so, to admit of its particles uniting, so as to take the regular forms under which it appears; and the substance which these crystals penetrate must have likewise been fluid, to admit of this penetration, and of these regular forms being assumed. It is likewise obvious, that of these two substances, the latter, or the substance which is penetrated, and often impressed by the regular forms of the other, is that which must have consolidated last: it must have remained liquid, while the crystals of the other substance shoot through it, and have consolidated around them after they had been formed. To determine the question, therefore, whether the previous state of fluidity had been that of fusion from heat or not, all that is necessary, is to discover which of those substances is most fusible; for if the substance which is penetrated or impressed be less fusible

than the one which shoots through it, it amounts to a perfect demonstration, that their previous liquidity could not have been from fusion; since, in this case, the impressed substance, being least fusible, must first have become solid, and the other could never have penetrated or impressed it. Now, it so happens, that in almost all the cases of this kind with which we are acquainted, the crystallized and impressing substance is more fusible than the one which is impressed. Gold and silver, which we can melt easily, shoot through quartz, which we find perfectly infusible, in the most delicate and multiplied ramifications: sulphuret of antimony, in long and slender prisms, penetrates sulphate of barytes, without the least deviation of their course: sulphuret of iron is imbedded in its regular cubic form in slate and in sienite: garnets, with the numerous planes and angles which their crystalline forms exhibit, are implanted in granite, or in mica slate: and actynolite and schorl in prisms penetrate quartz. It is needless to multiply examples, and equally so to attempt, by any farther illustration, to add force to the argument which these afford. If the conclusion to which they lead, that these substances have not consolidated from fusion, be not admitted, we may safely affirm, that no argument in geology can be relied on; for it is impossible to conceive a proposition more completely self-evident, or an inference more strictly deduced.

No difficulty, from the cases now stated, attaches to the supposition of these substances having consolidated from solution; for there are no appearances whence it can be inferred, that the crystallized and impressing substance might not be the one that first became solid,

Thus, both in their first principles and in their application to the phenomena of geology, and the properties of individual minerals, these systems exhibit a striking contrast. We can only admire, in the Huttonian hypothesis, the grandeur and beauty of the views which it brings before us ; but we discover, in the Wernerian system, more of the characters of a legitimate theory ; imperfect, no doubt, since the science itself is in an imperfect state, but inferred from the phenomena of the mineral kingdom by a cautious induction, and leading to the examination of these phenomena with a minute and patient attention.

CHAP. VI.

OF MINERAL WATERS.

MINERAL WATERS being complicated, and diversified in their composition, cannot be strictly placed under any of the established classes of chemical arrangement. But their history may with propriety follow that of the substances which belong to the mineral kingdom, as it is of combinations of these that they chiefly consist.

All waters, rain water excepted, might in strict propriety be named Mineral, as they all contain a slight impregnation of earthy or metallic matter, derived from the strata over which they have passed. But the term is restricted to those in which the impregnation is so considerable as to communicate taste or flavour, or the power of acting in a peculiar manner on the animal system.

The substances contained in mineral waters are very numerous. The principal are carbonic acid, sulphuretted hydrogen, sulphurous acid, carbonates, sulphates, and muriates of soda, lime, and magnesia, and carbonate and sulphate of iron. From the predominance of certain of these ingredients, mineral waters may be characterized; and they have thus been divided into four classes. 1st, Those in which carbonic acid is predominant, and which have usually been named Acidulous; 2d, The Sulphureous, the principal ingredient of which is sulphuretted hydrogen; 3d, The Chalybeate, or those having iron for their chief constituent; and, 4th, The Saline, in which various neutral salts are dissolved. In stating the methods of analysis, they may be conveniently considered under these divisions, adding a few observations on those substances which are of more rare occurrence.

Mineral waters of the first class, or those in which carbonic acid is predominant, are easily known by their sensible qualities. They sparkle when poured into a glass, and have an acidulous pungent taste; while these qualities are lost by exposure for a short time to the atmosphere. The quantity contained is very variable: it must in general be inferior to the volume of the water, and can be superior to this, indeed, only when its condensation is promoted by certain saline ingredients contained in the mineral water. The tests by which carbonic acid in a free state, or not combined with any base, is discovered, are sufficiently precise. The infusion of litmus is reddened, when the quantity of gas amounts to one-sixteenth of the bulk of the water, the redness being greater according to the quantity of acid. The experiment is best made, by

adding to a very dilute solution of litmus, an equal quantity of the water, in a tube not exceeding half an inch diameter, as the change is then best perceived.

In order, however, to render this test decisive, two circumstances with regard to it are necessary : 1st, That the redness should not be permanent, but should disappear after exposure to the air for some time, and be capable of successively disappearing, and being produced by fresh additions of the water, as it is thus distinguished from the more permanent redness given by other acids ; and, 2dly, That the mineral water should give a precipitate with lime water, soluble in the mineral acids with effervescence : this distinguishes carbonic acid from sulphuretted hydrogen, which likewise gives a transient red tinge to infusion of litmus. Lime water is a very sensible test of free carbonic acid, and always detects it by the cloudiness it produces : half a grain of carbonic acid may thus be discovered in 7000 grains of water.

To ascertain the quantity of carbonic acid existing in solution in any mineral water that is not combined with any base, the following process has been given by Kirwan. A small retort, whose capacity is known, is to be filled with two-thirds of its contents of the water to be examined, its extremity being placed under a jar filled with mercury, and divided into tenths of a cubic inch. The water is to be heated, and kept boiling for a quarter of an hour. To the air which has been expelled, and which is collected in the jar, a small quantity of solution of potassa is to be introduced, and the vessel agitated. The extent of absorption indicates the quantity of carbonic acid which the water contained ; the volume being

of course brought to the standard atmospheric pressure and temperature.

In some mineral waters, sulphurous acid is likewise contained, which the application of the heat will expel. This, however, is very rare : when it does occur, it may be previously discovered, by its smell, by permanently reddening the infusion of litmus, and by rendering colourless a tincture of red rose, previously reddened by an acid. Its quantity, when it has been expelled, may be ascertained by leaving the solution of potassa, to which it has been exposed, in the air for some days, and by evaporation, ascertaining the quantity of sulphate of potassa it contains ; or, what is a more expeditious mode, by gradually adding to the sulphurous gas small portions of sulphuretted hydrogen, as long as any diminution of volume is produced : the mixture of these airs, by their mutual action, produces water and sulphur ; and, therefore, by the diminution of volume, the quantity of sulphurous acid may be discovered.

Sulphuretted hydrogen existing in a water, forming the Sulphureous Waters, is easily discovered by its smell. It likewise reddens the solution of litmus. Water containing it becomes turbid from exposure to the air, and deposits sulphur, the hydrogen attracting oxygen. A similar change is induced in it by nitrous acid. A solution of acetate of lead is blackened by it ; and mercury or silver has its surface tarnished by being immersed in it.

Various methods of estimating the quantity of sulphuretted hydrogen have been employed, particularly the separating of it by the application of heat, and receiving it over water or mercury. But the separation in this way

is never complete, and the gas expelled cannot easily be collected so as to be measured, water absorbing it, and quicksilver decomposing it. The following method, therefore, has been proposed by Mr Kirwan. The sulphureous water is introduced into a jar, so as to fill three-fourths of its capacity, the remaining fourth containing atmospheric air; and to this, the jar being placed inverted in water, a few cubic inches of nitrous gas are introduced: nitrous acid vapour is formed, which decomposes the sulphuretted hydrogen, and precipitates the sulphur: the addition of the nitrous gas is continued, as long as red fumes are produced by its mixture with the atmospheric air over the water, and till the water in the jar has lost its foetid smell. The precipitation of the sulphur diffused through the water, is facilitated by heating it to 150° of Fahrenheit for half an hour, a few drops of nitrous acid having been added to prevent the precipitation of the earths. It is then filtered; the excess of weight which the filtre, when dried, has gained, will show the quantity of sulphur that has been deposited; and from this may be estimated the quantity of sulphuretted hydrogen; 100 cubic inches of this gas containing 30 grains of sulphur. The same precipitation of sulphur may be effected more easily by the affusion of very fuming nitrous acid on the sulphureous water; but, according to Kirwan, the acid soon becomes too dilute to precipitate it entirely. Sometimes sulphuretted hydrogen exists in a mineral water, along with carbonic acid. In this case, both gases may be expelled from the water by heat; and the mixed gas may be exposed in a tube to nitrous acid,

by which the sulphuretted hydrogen is decomposed, and of course absorbed.

In some cases nitrogen gas is contained in mineral waters. It was discovered in the waters of Buxton by Dr Pearson, and in those of Harrowgate by Dr Garnet. It may be discovered by its characters of not being absorbed by water, nor affected by eudiometrical processes.

The solid ingredients of mineral waters, which constitute the two remaining classes of Saline and Chalybeate Waters, are next to be ascertained. With these ingredients, the gases which have been already noticed, are indeed frequently combined; but in this case, in ascertaining their analysis, the gaseous substance is expelled, previous to submitting the water to the action of the necessary tests. The application of these, therefore, is in this case the same as in the example of a water purely saline or chalybeate, in which no aërial ingredient is contained.

The mineral acids, when not combined with any base, are discovered by giving a permanent red colour to vegetable infusions. These acids, uncombined, are however very seldom found. The sulphuric and muriatic, it is said, sometimes occur, being combined with some of the earths, so that an excess of acid is still present; but this is in very inconsiderable quantity. The boracic acid has been found in some lakes in Tuscany; but its presence must very rarely be expected in mineral waters.

The alkalis, if ever present in excess, may be discovered by their property of changing the vegetable colours to a green, or rendering that of turmeric brown.

The neutral and earthy salts are the chief constituents of mineral waters; and to discover these becomes ex-

tremely difficult. The first step is to reduce the quantity of water by evaporation, and then endeavour to discover the nature of the substances present by the use of tests. Mineral waters are in general so dilute, that this reduction is indispensable ; for in decomposing a compound salt, by the action of a substance capable of saturating its acid, if the quantity of water present be large, it may be sufficient to counterbalance the insolubility produced by the diminution in the action of the acid ; and the base may be kept in solution, partly by the solvent power of the water, and partly by the remaining action of the acid. Thus, Bergman found, that a salt with base of lime, when dissolved in fifty times its weight of water, suffers no precipitation from the addition of a fixed alkali, though this quantity of water is not by itself sufficient for the solution of the portion of lime it contains *.

We first endeavour to ascertain what acids exist in the water in a state of combination. The sulphuric acid is very frequently found in combination both with the alkalis and earths. It is detected by muriate, nitrate, or acetate of barytes or of strontites, acetate of lead, and nitrate of mercury. Muriate of barytes is the most delicate of these tests : a saturated solution of it produces a sensible precipitate in water, that contains not more than $\frac{1}{910.125}$ of its weight of real sulphuric acid. Acetate of lead is much inferior, giving a precipitate only when the water contains $\frac{1}{90.970}$ of its weight. The others are still less delicate ; and the nitrate of mercury is unfit to be employed, from the difficulty of obtaining it perfectly uniform

* Chemical Statics, vol. i. p. 59.

in composition. If it has an excess of acid, it is a test of little delicacy; and if perfectly saturated with the oxide, the water alone produces a partial decomposition and precipitation. The barytic salts have another advantage, that they give no precipitate with muriatic acid. In using them, however, there is one fallacy to be guarded against, —that arising from the presence of any carbonate, as this would immediately decompose the barytic salt, and a precipitate of carbonate of barytes would be formed. This is easily discovered, by the precipitate disappearing from the addition of a few drops of nitric or muriatic acid, or from its not taking place when such an addition, so as to cause a sensible acidity in the water, has been previously made. These tests, it is to be remarked too, are less delicate when the sulphuric acid is not free, but saturated by combination with any base. Yet even in this case their delicacy is very great. According to Bergman, a few drops of a solution of muriate of barytes produces a cloud immediately in a solution of 12 grains of crystallized sulphate of soda in $5\frac{1}{2}$ English pints of water; this quantity of that salt containing not more than 2.83 of real acid.

Muriatic acid, which is the one that next to the sulphuric exists most frequently in a combined state in mineral waters, is detected by the nitrate of silver. The power of this test is astonishingly great. One grain of muriate of soda, dissolved in 42.250 of water, that is, in rather more than 5 lbs. of water, is discovered by white streaks being produced in the solution by the addition of this test; this quantity of water not containing more than the $\frac{1}{100.333}$ part of its weight of real muriatic acid. The same test likewise occasions a precipitate with sulphuric

acid, though much less sensible. In using it, therefore, in the analysis of mineral waters, it is necessary to guard against this source of fallacy, by first decomposing any sulphates existing in the water by nitrate or acetate of barytes, after which the nitrate of silver may be used. It is likewise precipitated by the alkaline and earthy carbonates; and therefore, these ought to be decomposed by the previous addition of pure nitric acid, though the precipitates afforded by the operation of these salts are likewise known, by being soluble in nitric acid, which the precipitate from the muriatic acid is not. It is precipitated, too, by sulphuretted hydrogen; but the presence of this is always sufficiently obvious, and the precipitate which it gives is of a dark colour. This test is of such delicacy and certainty, that no other need to be had recourse to, though the acetate of silver has been used.

Nitric acid seldom exists in mineral waters even in combination. It is not discoverable by any test, but only by the properties of the salts which it forms.

Carbonic acid, in a state of combination with the alkalis or earths, is distinguished by the effervescence produced by adding sulphuric acid, and still better by muriate of barytes producing a precipitate, which is again dissolved by the nitric or muriatic acid with effervescence. The alkaline carbonates may be discovered by the power which they retain of changing the vegetable colours; the earthy and metallic carbonates, by being precipitated when the water is boiled, as they are retained in solution only by an excess of acid.

The preceding acids, which are those chiefly that exist in mineral waters, may be combined with the alkalis,

with earths, and with certain metals. The tests of these bases are lastly to be noticed.

The earths principally existing in combination with acids in mineral waters, are lime, magnesia, and argil. They may be discovered by the following tests.

Lime is immediately precipitated from all its combinations by oxalic acid; and the delicacy of this test is very great. A minute portion of it discovers one grain of pure lime in 42.250 of water, by forming a cloud, and a deposition of a precipitate in twenty-four hours. The only important fallacy to which this test is liable in analysis, is where some of the mineral acids exist in the water, or are disengaged by the decomposition which the oxalic acid itself makes: they either decompose this acid, and of course destroy its combination with the lime, or they dissolve the oxalate of lime. This may in a great measure be prevented, by using not the pure oxalic acid, but the oxalate of potash, which, though a less sensible, is on this account a more accurate test. It also precipitates magnesia; but in doing so it acts slowly, the precipitation taking place only after some hours, and not unless a large quantity of the magnesian salt exists in the mineral water; while from lime the precipitation is immediate, even when it is present in very small quantity. Any fallacy from the presence of barytes is scarcely ever to be looked for, and is easily discovered by diluting the water, and in this diluted state adding a little sulphuric acid. Sulphuric acid itself has been employed as a test of lime, when it exists in combination with any other acid; but it is one much less delicate, sulphate of lime being soluble in 500 parts of water, and being much more so when

there is even a slight excess of acid. Fluoric acid has been proposed, and will form a test more delicate.

Magnesia is discriminated with more difficulty by any test. It is precipitated by lime water and by water of ammonia; by the latter partially, by the former entirely. Both are liable to fallacies. Thus, with regard to lime, if any carbonate be present, the carbonic acid may be transferred to the lime, and a precipitate of carbonate of lime formed; or if a sulphate be present, there may, in like manner, be a precipitate of sulphate of lime. With regard to ammonia, if the magnesia exist in the mineral water in the state of carbonate, the ammonia may attract the carbonic acid, and this carbonate of ammonia re-acting on any salt of lime present, may give rise to a precipitate of carbonate of lime. Both these sources of fallacy may be avoided, however, by previously decomposing any carbonate, by the addition of a little nitric acid, and removing any sulphuric acid by muriate of barytes. But a source of uncertainty attending both tests, more difficult to be avoided, is, that they precipitate argil as well as magnesia. The method proposed by Mr Kirwan to discriminate between these earths, is to dissolve the precipitate thrown down by ammonia or lime water, in dilute nitric or muriatic acid, and again precipitate it by an alkaline carbonate; this precipitate is to be dried in a heat of 90° or 100° , and then exposed to the action of dilute sulphuric or muriatic acid. The magnesia is thus quickly dissolved, while the argil, if present, is scarcely touched. A preferable method probably is, to boil gently the precipitate in a solution of pure potassa, by which argil is dissolved, while magnesia is not.

By the use of these tests, argil, it is obvious, existing in combination in mineral waters, may be discovered. It is also discovered by succinate of ammonia, which precipitates it without precipitating magnesia.

Barytes has been alledged to be found in mineral waters, combined with muriatic acid. It is easily detected by sulphuric acid, observing the precautions already stated under lime, but its presence is rarely to be expected.

Silex has been found in some mineral waters, particularly in hot springs ; not, however in combination with any acid, but either merely dissolved by the water, by the aid of the high temperature, or by the medium of a small portion of alkali or alkaline carbonate. It is discovered by evaporating the water nearly to dryness, and adding to the residual matter nitric or sulphuric acid, and again evaporating. If the dry mass obtained by this second evaporation be dissolved in water, the siliceous earth will remain undissolved, and may be discovered by the gelatinous consistence it assumes when not quite dry ; by its insolubility in every acid except the fluoric ; and by vitrifying when heated, with the addition of two parts of soda, by the blow-pipe.

The alkalis, in a state of combination, in mineral waters, cannot be discovered by tests equally striking as those by which we discriminate the earths. But their presence is inferred, when acids are discovered in a water which are not free, and which at the same time, from the application of tests, do not appear to be in any other state of combination. The volatile alkali is seldom or never present. Potassa may be distinguished from soda by the nature of the salts which it forms. The differences be-

tween some of these are sufficiently obvious, and furnish tests of some nicety. Thus, the compound of soda with tartaric acid is easily soluble in water; while, when the same acid is added to a solution of potassa, it forms not the soluble neutral salt, but the acidulous tartrite, which is of sparing solubility. Oxalic acid affords a test still more delicate. Soda forms with it a salt not soluble, but in comparatively a large quantity of water; while potassa, with the same acid, forms a soluble salt. Dr Henry has remarked, that muriate of platina affords an excellent test to discriminate between these alkalis; as, with the smallest quantity of potassa or any of its salts, it forms an immediate precipitate, while it is not at all affected by soda.

Besides the earths and alkalis, the acids in mineral waters are sometimes combined with metallic oxides, at least with oxide of iron. The salts of copper are sometimes found in the waters which issue from mines; and muriate of manganese was observed by Bergman in some waters in Sweden, and has been more lately discovered in the waters of Lemington Priory by Mr Lambe. The salts of iron, however, forming the last division of mineral waters, the Chalybeate, are those of common occurrence, and they are extremely frequent. The iron is generally kept in solution by the carbonic acid, though sometimes also by the sulphuric.

The tests by which we discover this metal, are both delicate and unequivocal. These tests are, infusion of galls, and the alkaline prussiates.

The infusion of galls is a test extremely sensible. If three grains of crystallized sulphate of iron, which con-

tain about one twenty-fourth of a grain of the metal, be dissolved in $5\frac{1}{2}$ English pints of water, the solution strikes a purple colour in five minutes with one drop of the tincture; hence it discovers in water a quantity of iron, amounting only to $\frac{1}{47.789}$ of its weight. A sensible tinge is even said to be produced with one grain of the sulphate dissolved in 15 gallons of water. Its delicacy is equally great when the lime is dissolved by carbonic acid. The tint of colour is varied by the presence of other salts. Thus, if the water contain an alkaline carbonate, it is violet; if neutral alkaline salts, dark purple; if earthy salts, violet; if sulphate of lime, the precipitate is at first whitish, and afterwards black; and if sulphuretted hydrogen, the tinge will be a purplish red. Mr Philips has shewn, that carbonate of lime has a considerable effect on the production of colour by the action of infusion of galls on salts of iron. When the iron is in a low degree of oxidizement, it rather heightens the colour; while, when it is at the maximum of oxidizement, it diminishes it so much, that if the iron be present in very minute quantity, it may even not be capable of being detected by this test. And he has thus been enabled to explain a fact before inexplicable, and which had given rise to various opinions with regard to the waters of Bath,—that when taken immediately from the spring and while hot, they give indication of a small quantity of iron, by the test of infusion of galls, while, when they have cooled under exposure to the air, so that the iron becomes more oxidized, they appear, from the same test, to contain none, though no iron is deposited during the cooling*.

* Analysis of the Bath Water, p. 17.

By applying this test before and after the ebullition, we discover whether the iron is dissolved by carbonic or by sulphuric acid ; since, if the colour is not produced after ebullition, and when the liquor has cooled and become clear, it is a proof that carbonic acid has been the solvent, the heat having expelled it, and the oxide of iron been precipitated. If, after such a precipitation, the liquor still strike a purple colour with tincture of galls, it is probable that both sulphate and carbonate of iron have been contained in the water.

Prussiate of potassa, or the triple prussiate of potassa and iron, in that state in which it gives no blue precipitate with an acid, has been used as a test of iron ; as it produces, when it is present, a blue colour, and a blue precipitate gradually subsides. Independent, however, of some sources of fallacy, from the presence of other substances, as of any free alkali which prevents the blue colour from appearing, the test itself is liable to fallacy from its composition. The triple prussiate contains a quantity of iron essential to its composition ; and when an acid is evolved, this is liable to give rise to the blue precipitate, even though iron should not be contained in the mineral water, at least unless the test be well prepared. And the pure prussiate of potassa, which is free from this source of error, is an inconvenient test, from its extreme susceptibility of decomposition, which renders it difficult to be preserved. Either of them has one advantage, that of indicating the presence of other metals, by the precipitates it forms from the metallic salts. Succinate of soda or ammonia has been more lately used as a test to dis-

cover the presence of iron, and determine its quantity, as is to be immediately stated.

Besides the method of discovering the saline compounds existing in mineral waters, by tests indicating their acids, and the bases with which these are combined, the compounds themselves may sometimes be discovered more directly, by separating them in their entire state, by the agency of alkohol, which weakens the solvent power of the water, or by partial evaporation.

When the water is strongly impregnated with saline matter, or when it is concentrated by evaporation, those salts, which are least soluble, and on which alkohol exerts no solvent power, are precipitated by the affusion of this liquid, and may thus be frequently recognised. This is very well shewn in the experiments of Boulduc, by whom this test was first employed. To eight parts of a mineral water which he had submitted to analysis, he added eight of alkohol, and found sulphate of lime to be immediately precipitated. Pouring the clear water into another vessel, five parts more of alkohol were put to it, and sulphate of soda was thrown down; and, lastly, on the addition of five parts more of alkohol, muriate of soda was deposited. In general, the sulphates are most readily precipitated by this re-agent. Sulphate of lime is thrown down when present in water in the proportion of not less than 1 in 1000 parts, by alkohol, the specific gravity of which is not greater than 850. The alkaline sulphates in the same proportion may be precipitated, but slowly, by alkohol of the specific gravity of 817, and, if in a greater proportion than $\frac{1}{740}$, are readily precipitated by it when its specific gravity is even above 834. Alum

and sulphate of magnesia must be in a greater proportion than $\frac{1}{40}$ to be precipitated by alkohol of this strength.

Besides these, carbonates of lime and of magnesia are thrown down, nearly as readily as sulphate of lime, if the specific gravity of the alkohol is as high as 817.

Alkohol is not less useful in the analysis of mineral waters from its solvent power. This application of it was first made by Lavoisier. The saline matter of any mineral water is obtained by evaporation: eight times its weight of alkohol, of a determinate specific gravity, is added to it; a separation of the salts present will probably be effected. Those soluble in alkohol being dissolved, by evaporation of the alkohol and subsequent solution in water, they may be recognised, and thus the analysis is much facilitated. The salts most soluble in alkohol, which are to be looked for in mineral waters, are muriates of magnesia, lime, argil, and iron, and nitrates of magnesia and lime. The sulphates and carbonates are in general insoluble, or at least are of very sparing solubility. Tables, founded on an extensive series of experiments, of the solubility of different salts in alkohol, have been given by Kirwan in his treatise on Mineral Waters.

Evaporation is another method by which a number of the compound salts existing in mineral waters may be discovered. Some are deposited even while the evaporation proceeds, or at least after it has been carried a certain length, and the liquor is allowed to cool; such as sulphate of lime, and carbonate of lime or of magnesia. Exposure to the air, too, of the liquor evaporated to a certain extent, causes a separation of some ingredients; the earthy carbonates are thus deposited, and carbonate

of iron is decomposed, the iron passing to a higher state of oxidizement, so as to be no longer capable of being retained in solution by the acid, and the oxide being therefore precipitated. When these substances have been thus separated, the water is evaporated to dryness, and the dry mass is then subjected to the action of a small quantity of water, by which its saline ingredients may be separated, and either detected more easily by tests, or crystallized.

This method, too, is frequently conjoined with the action of alcohol and other re-agents. The water is evaporated to dryness, and the weight of the dry matter ascertained. Eight or ten parts of alcohol are poured upon it, and after having stood some time, and been agitated frequently, the whole is thrown on a filtre, to separate the undissolved matter. This is dried, and its weight ascertained. It is then submitted to the action of cold water; and afterwards the matter which remains undissolved, is boiled with at least 500 times its weight of water. If there is any residuum after these operations, it may consist of lime, magnesia, argil, silex, or oxide of iron, or a mixture of these. The two first may be dissolved by digestion in distilled vinegar; the argil and the oxide of iron may be dissolved by dilute muriatic acid; and the silex will remain unaffected by any of these re-agents.

By these separations of the ingredients of the mineral water, their examination is much facilitated, especially when, by the previous application of tests, information has been obtained as to the principles the water contains.

The process is no doubt also, however, liable to some sources of error, particularly from the re-action of the substances on each other, when the solution is concen-

trated by the evaporation. Salts often exist in a mineral water, which from their state of dilution do not decompose each other, but which, when more concentrated, give rise to such decompositions and consequent formation of new compounds. With regard to this, it is at the same time to be observed, that it is very doubtful, from the views of affinity which have been already given, whether salts obtained from a mineral water exist in it in those binary combinations under which they are separated by crystallization, or other methods. It is rather to be inferred, from Berthollet's doctrines, that their acids and bases exist merely in one state of combination, producing mutual neutralization, and that such combinations are established from the force of cohesion, by the processes by which they are procured. In this point of view, the above source of error is of less importance; since, if it be just, the only legitimate inference we can draw from the analysis of a mineral water is, that certain acids and certain bases exist in it, not, as has been hitherto believed, that it is a solution of certain compound salts fully formed: and the same observation applies to the source of error supposed to attend this method, from the mutual action of the salts in promoting their solution in one solvent.

Some information, which may serve as a guide in the analysis of mineral waters, it has been supposed, may be derived from the knowledge of what are named Incompatible Salts, that is, salts which cannot exist together without producing decomposition and precipitation; as, if certain salts of this kind are discovered, it may be inferred, that others which are thus incompatible with them cannot be present. Thus, carbonate of soda and sulphate

of lime, muriate of lime and sulphate of magnesia, muriate of lime and sulphate of soda, it might be concluded, could not exist together. But the accuracy of such conclusions is altogether invalidated by the fact, that salts known to be incompatible, if their solutions were mixed in a concentrated state, are not so in a state of great dilution, owing no doubt to the solvent power of the water, increased by its quantity, on their principles, in consequence of which the power of cohesion, that determines to binary combinations, is sufficiently counteracted, and the salts above enumerated, with others usually considered as incompatible, have accordingly been discovered together in many mineral waters.

After discovering the substances which exist in a mineral water, the remaining step to complete the analysis is to estimate their quantities. The methods by which the aerial principles are separated, and their quantities determined, have been already stated; and it remains only to make a few observations on the modes of ascertaining the quantities of the solid ingredients.

This is in general effected by the process of evaporation, conjoined with the operation of alkohol and other re-agents, as already described; the substances which separate when the evaporation is carried to a certain extent, or which are precipitated by alkohol, being collected and weighed, and those which are obtained insulated by the solvent power of alkohol, by water successively applied in different quantities and at different temperatures, or by the action of acids, being in like manner reduced to a crystallized or desiccated state. To these methods, which are always liable to some fallacies, as has been already

stated, has been added by Mr Kirwan the mode by estimation, founded on the production of certain compounds, the composition of which, with regard to the proportions of their elements, has been determined with precision. Thus, the quantity of sulphuric acid contained in a mineral water may be determined, by adding barytic water, or nitrate or muriate of barytes; the whole of it being precipitated in the state of sulphate of barytes, and the proportion of sulphuric acid, which a given weight of this brought to a certain state of desiccation contains, being known. The quantity of muriatic acid may equally be determined in the same way, by the quantity of muriate of silver obtained by adding nitrate of silver to the mineral water; and the quantity of carbonic acid, by the quantity of carbonate formed by the addition of barytic or lime water. The quantities of certain of the bases may be discovered in a similar manner: that of lime may be discovered from the quantity of oxalate of lime precipitated by the addition of an oxalate, and that of magnesia or argil by the direct precipitation of these earths by ammonia or lime-water. The quantity of oxide of iron used to be ascertained by allowing the water to remain exposed to the air, until it was entirely precipitated: it has also been determined by the weight of the precipitate produced by the addition of an alkaline prussiate; or by a method more lately introduced,—that of precipitating it by succinate of soda, and decomposing the succinate of iron, by exposing it to a low red heat, with the addition of a little wax, by which the quantity of oxide of iron it contains is ascertained: this oxide containing about 70 per cent. of iron: if this last method be employed, it is to be observed,

that argil is likewise precipitated by the succinate if there be no great excess of acid present ; and hence, any error from this must be guarded against. When the quantities of those bases which can be determined in this manner have been discovered, and the quantities of the acids present are also ascertained, we discover whether these are in those proportions which produce the state of neutralization, and therefore, whether other bases not producible in this method, as the fixed alkalis, are present, when of course other methods are had recourse to, from which the quantities of these are determined.

There can be no doubt, that this method by estimation of determining the quantities of ingredients, is liable to errors, from the uncertainties which attend the determination of the proportions of the constituent parts of compound salts. But it may be combined with the other methods ; and indeed, it is only by such a combination that the errors attending a complicated analysis can be diminished, and an approximation to accurate results obtained.

I have thus given a general view of the methods of analysing mineral waters. To enter on all the details on this subject would require a distinct treatise ; and an abridged view of the niceties of manipulation, and the precautions necessary to be observed with regard to the various cases that may occur, would be of little utility, or rather, indeed, is impracticable. For these, therefore, I refer to the treatises of Bergman and Kirwan.

END OF VOL. III.

